MILITARY ENGINEERING.

(PART IIIA.)

ITARY BRIDGING—GENERAL PRINCIPLES AND MATERIALS.

GENERAL STAFF, WAR OFFICE, 1913.

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MILITARY ENGINEERING.

(PART IIIA.)

MILITARY BRIDGING—GENERAL PRINCIPLES AND MATERIALS.

GENERAL STAFF, WAR OFFICE, 1913.

LONDON:
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E W D Ward

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PART IIIA.

MILITARY BRIDGING—GENERAL PRINCIPLES AND MATERIALS.

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SECTION I.—RECONNAISSANCE.

1. The operations of an army in the field often involve the passage of a river or similar obstacle at points where no bridge exists. As a rule some information about the obstacle is obtainable from maps and reports prepared in peace, but such information should be checked and supplemented by further reconnaissance.

The choice of the spot for effecting a crossing will usually be limited by tactical requirements, to which all other considerations must, as far as possible, give place. The first essential, therefore, is the issue of definite instructions by superior authority as to the tactical object of the reconnaissance.

It is only when this is known, and when sufficient time has been allowed in which to carry it out, that the best sites for the passage can be selected, due regard being had to technical requirements and the materials available.

2. From a tactical point of view, the reconnaissance should aim at obtaining information as to :—

(1) The general nature of the obstacle and of the district through which it passes.
(2) The available sites for a passage.
(3) The accessibility of the sites on both sides of the obstacle.
(4) The extent to which the ground on both sides lends itself to covering or disputing the passage.

3. It will rarely be possible to find a spot which fulfils all the requirements of a good crossing place. Even if such a place existed, it is probable that the enemy would take special measures to oppose a crossing at that spot, and it might be advisable to select another site. This consideration should not, however, prevent the characteristics of a good crossing place being borne in mind.

In an advance the near bank should afford cover for preparing the bridge, for which purpose a tributary stream is useful, and it should command the far side. The latter condition will generally be found to exist at a re-entering bend, which also enables a converging fire to be brought to bear on the opposite shore. The country on the far side should be open to allow of a rapid advance. The existence of tactical localities at a suitable distance from the point of passage to secure and cover the crossing will add to the value of the site.

There should be no positions overlooking the selected point of passage which could be occupied by the enemy. In the case of a large river, any islands which would assist the operation will require consideration.

In a retreat, the country on the side from which the withdrawal is being made should offer facilities for defence, and should be such that the enemy is unable to fire on the point of passage.

From the technical point of view particulars on the following matters are required :—

(1) A section of the obstacle, showing the angle and height of the banks and the soil of which they consist.
(2) The length and nature of the approaches required on both banks (*see* para. 5).
(3) The nature and amount of materials available locally which are likely to be useful.

If part of the obstacle be water :—

(4) Whether it is tidal or not, and, if so, the amount of rise and fall.
(5) Whether there are indications of floods and their extent.
(6) The rate of the current.
(7) The nature of the bed.
(8) Whether the obstacle itself carries traffic.
(9) Nature, depth and suitability of any tributary streams near the site selected.
(10) Suitability of any islands as supports to the bridge.

Passage of rivers.

4. A river or similar obstacle may be crossed by fording ; on ice ; by using boats, rafts or flying bridges ; or by bridging.

Each method has certain advantages and disadvantages, of which the principal are mentioned in the following sections :—

(*a*) *Fording.*

Fords.

Advantages.—

Saving of time in preparation and use.
Practically no material required.
Considerable chance of secrecy.

Disadvantages.—

The possibility of the passage being interrupted by the rising of the stream.

The chance of the depth being increased beyond permissible limits by the passage of the troops.

The minor one of getting men and material wet.

The very limited extent to which fords are available for mechanical transport.

Fords are found more often in streams where the current is rapid than where it is slow, and in straight reaches rather than at bends. Rivers which are not fordable straight across may sometimes be found passable in a slanting direction between two bends, as at AB (Pl. I, Fig. 1). In searching for a ford of this character the river should be entered at the point A, and a direction taken which will lead to B, the points A and B being equally distant from the bends.

Paths or roads leading to a stream and at right angles to its course often lead to fords, and the continuation of the road or path on the other side of the stream should always be looked for.

Fords are very often found just below weirs.

A ford to be passable for infantry should not exceed 3 feet in depth; for cavalry, 4 feet; and for carriages containing ammunition, 2 feet 4 inches. When the current is very rapid a ford of less than these depths should be sought.

The bottom of a ford should be firm and even. A sandy bottom is undesirable, as the sand gets stirred up, and the depth of water is thus increased.

The upper and lower limits of a ford, at which a large force is to cross a stream, should be marked by large stakes driven into the bed, their heads being connected by stout ropes. The stakes should be marked at a height of 3 and 4 feet above the bottom, to show any rise in the water above the fordable depth.

The bottom should be made as even as possible, any large stones being removed. If necessary the banks must be cut down to give easy slopes.

(*b*) *Crossing on Ice.*

Crossing on ice.

Advantages.—

Little or no preparation or material required.

Variety of crossing places.

Chance of secrecy.

Disadvantages.—

Possibility of interruption of passage due to weather changes.

Occasions may arise when it is possible to cross a stream on the ice. The actual route selected should be free from large cracks and rotten ice, and the water must support the ice at all points.

Sound ice 3	inches	thick	will	bear	infantry at good intervals.
,, ,, 4	,,	,,	,,	,,	cavalry ,, ,, ,,
,, ,, 6	,,	,,	,,	,,	field artillery.
,, ,, 12	,,	,,	,,	,,	any load that an army is likely to have with it.

The route to be followed should be marked by cairns or bushes put in holes on either side. Some sand or earth, if obtainable, should be spread on the ice to improve the foothold; where nothing else can be got, loose snow may be used. Where sledges are to cross, a roadway, free of sand, should be provided.

An important point to be attended to is the edge of the ice. It will usually be advisable to make a shore bay of timber 10 or 12 feet long from the ground on to the ice on either side in order to avoid the edge. The ends of the road-bearers should be supported on planks in order to spread the load as much as possible. A short ramp of snow will be required from the shore bays on to the ice.

During the passage of the troops a watch should be kept in order to detect the formation of cracks; these are not of much importance, unless the water rises through them. Vehicles may be taken over ice, which would otherwise be too thin, by making their wheels run on planks laid lengthwise to spread the weight.

When the temperature is very low, and time permits, the thickness of the ice may be increased:—

(1) By covering the route with alternate layers of straw and branches, laid at right angles to each other, and watering them in order to freeze the whole into a compact mass.

(2) By enclosing the roadway between two rows of timbers, &c., pouring water between them and allowing it to freeze.

(c) *Boats, Rafts or Flying Bridges.*

Advantages.—

Saving of time in preparation.

Small amount of material required.

In the case of boats and rafts, a larger margin of action, giving great chances of secrecy.

Ability to pass over heavier loads than will usually be possible with bridges.

Disadvantages.—

Slowness in use.

When there is insufficient material to make a bridge, when a ferry only is required, when time is a factor, or when equipment too heavy for an ordinary bridge has to be moved over water, rafts or flying bridges may be used for the personnel and equipment, while the horses are made to swim.

A raft can be made of pontoons, boats, barrels, timber, of inflated skins or bladders, or of cases or frames of wood or wicker work covered with canvas, &c., and either filled with hay or left empty.

It may be rowed, poled or hauled across the stream by a hawser; but a raft is almost unmanageable in a rapid stream, unless made of pontoons or boats, and even then it requires skilful handling.

A flying bridge consists of a boat or a raft of two piers, which is made to move across a stream by the force of the current acting obliquely against its side. Long, narrow, deep boats with vertical sides, to which lee boards can be attached, are most suitable for the purpose. Their use should generally be confined to straight reaches where the current is free from irregularities, and has a velocity of at least two miles an hour.

If there is time and materials are available, horses can be made to cross attached to an endless rope.

If possible, a place should be selected where the banks shelve and the bottom is hard on each side of the river. This is almost essential for the landing side.

The materials required are a $\frac{3}{4}$-inch steel wire rope (endless ends joined by long splice), the minimum length of which should be equal to twice the width of the river plus about 70 yards, pickets for holdfasts, four snatch blocks and a tackle. Collars of spun yarn must be bound round the wire rope and fastened by passing the ends through the strands. These collars should be placed at central intervals of 2 feet 3 inches and extend for 6 inches each. They prevent the head ropes slipping and also serve as grips for the men hauling on the rope. When wire rope cannot be obtained a hemp one may be used, and 2-inch is a convenient size.

A party of 1 officer and 35 men is sent across the river with two snatch blocks, pickets for two holdfasts, two mauls and one side of the endless rope. This is arranged as shown on Pl. I, Fig. 2; 10 to 15 men are required on the starting side to work the rope and 4 men as lashers. Each horse having been stripped, except for head collar and head rope, is fastened by one of the lashers—walking backwards—to the endless rope on the down stream side by means of a draw hitch made with the head rope (Pl. I, Figs. 3 and 4), the length of which must not exceed 18 inches when the horse has been secured. The horses should be tied on at intervals of three or four horse-lengths (8 to 10 yards), and care must be taken that the head rope is tight on the endless rope. On the landing side 25 men will be required to pull on the rope, which they should do hand over hand and as quickly as possible. Four men with clasp knives receive the horses, and must be ready to cut any head rope knot that jambs. Six men take the horses from the receivers and lead them away.

If snatch blocks are not available more men will be needed,

and the horses should only be sent across two or three at a time.

Care must be taken that the rope is kept as taut as possible and moving faster than the horses can swim, *i.e.*, the rope must pull the horses and not *vice versâ*. A good average pace is 100 yards a minute.

(*d*) *Bridging.*—

Advantages.—

Greater rapidity in use than any other method.

Disadvantages.—

Large amount of material required.
Slowness in preparation.
Small chance of secrecy.

In bridging operations a distinction must be drawn between the bridges used with the field army and those on the line of communications. In the former case rapidity will be of the first importance, and elaborate structures will be out of place. With the field army tactical requirements must always be the chief consideration not only when deciding upon the locality where the river is to be crossed, but also in determining the design of the bridge. On the line of communications tactical considerations will have less weight and technical will gain in importance.

In field operations it will often be necessary to select a site for a bridge where facilities for its defence are of primary importance. These conditions will generally be found to exist at a point where the river forms a salient towards one's own side. As a rule, however, a bend is not a good position for a bridge from a technical standpoint, for the depth is variable and the bank on the outer side of the salient is apt to be steep, while the opposite one is often low-lying and marshy, so that on both sides difficulty may be experienced in making the approaches.

An army carries a certain amount of bridging material with it in the field. This material is intended for rapid bridging near the front, and whenever any of it is used it should be replaced as soon as possible by improvised material so that it may again be available.

General classification of military bridges.

Speaking generally military bridging may be divided into three main classes :—

I. *Light bridges.*—Bridges of the very lightest description, only intended for very temporary use, and meant for the passage of men in small numbers only.

Such bridges will most likely be required at the actual front itself or in close proximity to it. As a rule they would have to be made very rapidly and of improvised material.

II. *Medium bridges.*—Bridges capable of carrying men in fours, horses, field artillery and other similar loads.

Such bridges will most likely be required behind the front but in the tactical field of operations. Where possible they would be constructed of the special bridging equipment carried by an army.

III. *Heavy bridges.*—Bridges capable of carrying any of the vehicles accompanying an army in the field.

Such bridges will generally be required on the line of communications. They may be constructed of the army bridging equipment, but this should be replaced as soon as possible by improvised material.

In all three classes the principles of construction are the same, the only difference between them being in the size of material. It is therefore unnecessary to differentiate between the classes in the remainder of this book. For any particular bridge details of the technical requirements are given in subsequent sections.

5. The approaches at both ends of a bridge or other crossing place are a matter of great importance. From a technical point of view the approaches to a bridge will very often be the deciding factor as regards its site. They must be so formed that all the traffic which the bridge is designed to carry can pass along them without difficulty.

Easy access and a difficult exit are liable to cause crowding at the entrance to and on a bridge, which may lead to accidents and delay. An easy exit is, therefore, essential.

When possible the approaches should be in prolongation of the line of the bridge for at least 20 yards. If this is impossible the roadway should be widened considerably. If ramps on to the bridge are necessary their gradients should be easy and never steeper than 1 in 7, while for animals slopes steeper than 1 in 10 should be avoided. Where long wheel base vehicles with low bodies, such as motor cars, have to cross, if the angle between the ramp and the bridge is a salient one, it should be eased off.

SECTION II.—NATURE AND MEASUREMENT OF GAPS TO BE BRIDGED.

Nature of gaps.

1. Gaps to be bridged will differ in their width and depth, in the nature and slope of their sides, in the fact of containing water or not, and in the depth and current of that water.

Measurement of gaps.

2. The site for the bridge having been selected, it is generally necessary to measure the width of the gap, and if the bottom is to be used for supports to ascertain its section before commencing work.

Direct measurement of the width of the gap by means of tape, wire or line gives the best result. Over water, boats or floats may be used to support a long line. If direct measurement is not practicable, resort must be had to a geometrical method (*see* "Military Engineering," Part I, para. 23 (*g*)). One of the simplest of these is shown on Pl. II, Fig. 1. There AC is the line of proposed bridge. CD is laid out at right angles to AC, D being taken at any convenient distance. Then DE is laid out at right angles to AD and meets AC produced in E.

Then $AC = \dfrac{CD \times CD}{CE}$, and AB, the width of gap, is obtained by deducting BC from AC. This method involves only the laying out of two right angles and the measurement of two lines.

If the gap does not contain water the section can be obtained by direct measurement below an actual or visual line joining the two banks. If the gap contains water soundings must be taken. If the stream is not very wide or rapid a line marked at equidistant points can be stretched across, and from each of the points the depth of water taken by means of a boathook or sounding line.

Another method of using a sounding line is as follows :—

Get one man across the water with the line B′ (Pl. II, Fig. 2). Pass the sounding line C through the float A and attach the plummet D. Pay out the line B and haul on B′, and take soundings every 5, 10 or 15 feet as required, getting the width of stream at the same time. The float lines BB′ must be well stretched before they are marked off and used.

In taking soundings haul the sounding line up smartly until the lead hits the float and then lower away sharply, measuring the length let out with a rod marked in feet and inches. This should be done two or three times for each sounding.

If the current is very rapid it will be necessary to hold the ends of the lines BB′ some distance up stream, so as to get the float on the section line.

The sounding line must be fine and run very easily through the hole in the float. It should be kept on a fishing reel and be treated with the care given to a fishing line. A heavier lead will be required in deep and rapid water.

In a broad river with a strong current it may be necessary to take soundings from a boat, and to observe from the shore the points at which the party in the boat takes them.

The following method may be adopted :—Let AB be the line across a river on which a section is to be made (Pl. II, Fig. 3) ; fix poles in line at A, B and H. Lay off a straight line BD at right angles (or nearly so) to AB ; select a point C on this line, so that BC is a convenient multiple of CD (say equal to twice CD) ; erect poles at C and D. Lay off from D the line DEF parallel to ABH ; erect a pole at E in prolongation of AC.

If then a boat be moored at any point in the line AB, as K, an observer on the line DE (who moves so that the pole C shall always keep in the line with his own eye and some mark on the boat) will be at the point M. Drive a picket at M, then BK= 2 DM. The sounder at K can signal to the observer on the line DE at what moment he wants the position of the boat fixed. Other points can be fixed in a similar manner.

This method is not practicable when the banks of the river are steep or thickly wooded. In these cases the positions of the boat may be found by measuring a distance BC (which should be a multiple of 100 for convenience) at right angles to AB, and using a sextant and table of tangents.

Occasions may arise in bridging streams when either there is no time to take soundings (as in rapid bridging with light materials) or the means of doing so are deficient. In such cases all that can be done is to ascertain the approximate depth of the site for the next support from the last one placed in position by means of a pole (allowing for the slope), and adjust the height of the support after it is in position.

To measure the velocity of a stream, the simplest plan is to use a light deal rod, weighted so as to float nearly vertically with its tip above water. Note the distance it floats in a given number of seconds ; then $\frac{7}{10}$ the mean number of feet a second gives the number of miles an hour, in which terms the velocity should be stated.

*Classification of Bridges.**

3. The type of bridge to be used will depend on the nature of the gap and the material available. The various kinds of bridges in use may be divided into three classes as follows :—

I. Bridges without intermediate support.

Simple beams	can be used	for gaps	up to	about	25	feet.
Trussed beams	,,	,,	,,	,,	30	,,
Frame bridges	,,	,,	,,	,,	45	,,
Girders	,,	,,	,,	,,	60	,,

* All the bridges referred to are for road traffic. Railway bridges in the field are almost invariably simple beams on fixed supports, and are dealt with in Section XII of Part III, B.

Tension bridges can be used for gaps up to about 80 feet.					
Cantilever bridges	,,	,,	,,	,,	120 ,,
Suspension bridges	,,	,,	,,	,,	300 ,,

The nature of bridge to be made use of in any particular case will vary according to the width of the gap and the material available.

In the field it is very unlikely that any of the above bridges would be constructed with a longer span than 300 feet.

II. Bridges provided with intermediate supports.

By the use of supports the length of bridge is only limited by the amount of material available, and is not dependent upon the nature of the bridge. The built-up supports may be of many different kinds—heaps of stones, pieces of timber laid horizontally (cribs) or placed vertically resting on the bottom (trestles) or driven into the bottom (piles), &c.

III. Bridges resting on floating supports.

For military purposes, where time is an important factor, and where the materials available are limited, the usual form of bridge will be the simple beam supported on floating or fixed piers of all sorts. All the other forms of bridge take time or require special material, and their use will, as a rule, be confined to the line of communications.

Parts common to all Bridges.

Bays. **4.** The portion of a bridge between two points of support is termed a "bay." A bridge may, therefore, consist of one or more bays.

Transoms. The points of support vary according to the type of bridge, but on the top of each there is a member, usually a timber baulk, called a *transom* (in pontoon equipment or boat piers a *saddle*), which forms the support for the ends of the *road-bearers*.

At the ends of the bridge something firm must be provided for the road-bearers to rest on, *e.g.*, the top of a retaining wall. If nothing like this exists a *shore transom* (Pl. III, Fig. 1) should be used for the purpose well bedded in the ground, at a sufficient distance from the edge of the gap to prevent the earth breaking away under the pressure. This distance will vary according to the nature of the soil from 1 foot to about 6 feet.

Road-bearers. The road-bearers (in pontoon equipment and floating bridges *baulks*) consist of a number of longitudinal members, on which the flooring of the bridge is carried.

The number of road-bearers will vary according to their strength (Secs. III and IV). They are usually spaced evenly over the width of the roadway, but in narrow bridges and those intended for very heavy traffic (*e.g.*, traction engines) it may be advisable to group most of them under the wheel tracks.

In almost all bridges the road-bearers of adjoining bays will over'ap on the transom. They should be from 1 foot to 3 feet longer than the bay. In order to keep the bridge uniform they should be arranged in one of the methods shown on Pl. III, Figs. 4 and 5. When round spars are used, care must be taken that the ends of road-bearers on any transom are either all butts or all tips.

The best way to fasten the road-bearers to the transom is with bolts, spikes or nails. In any case, the outer road-bearers must be fastened, and it is advisable to fasten all. Lashings of wire or cordage may also be used.

The flooring of a bridge is generally made of wooden planks. Flooring. Those supplied for the bridging equipment are termed *chesses*. These planks or chesses are placed across the line of the bridge, resting on the road-bearers.

They should be from 12 to 18 inches longer than the width of the roadway. If those available are longer than is necessary, cutting may be avoided by laying them diagonally. The best way to fix the planks is to nail them down to the road-bearers. As a rule it will be sufficient to nail them to the outside road-bearers only, but if they are warped intermediate nails will be required.

Another method of fixing the planks is to keep the ends firmly pressed down on the outer road-bearers by placing ribands over them and racking the outer road-bearers and ribands together, as described in Sec. VII of Part III, B. This should be done at intervals of about 5 feet, and at these points the planks should be notched by cutting away a piece of the corner about 1½ inches wide and 10 inches long. This notch is made to allow a rack lashing to be passed down inside the riband. In the pontoon equipment every chess is notched.

Another method of holding down the ribands and planks is to make fast a rope or wire to the road-bearer, and lash the riband and road-bearer together diagonally (Pl. III, Fig. 3). This requires every plank to be notched.

If only thin planks are obtainable it will be advantageous to nail planks longitudinally to the flooring in the wheel tracks. These will spread the load and save wear on the cross planks.

In laying planks each man of the carrying party brings up a plank at a time, under the right arm, keeping the rear end well down, and advances by the right side of the bridge; when at the end of the finished part, he wheels to the left, bringing the plank across the bridge, and hands it to two men who stand on the outer road-bearers facing the shore, who lay it down on the road-bearers. The men who have brought up the planks pass off the bridge by the left, so as to avoid meeting those coming up.

If material is available the flooring should be continued for a short distance on the banks at each end of the bridges in order

to accustom horses to the noise, and to prevent the ground being cut up. Straw or rushes, in the absence of sawdust, moss litter, &c., may be spread to prevent slipping and deaden noise. If earth is used it should not be less than 3 inches thick, and allowance must be made in calculations for its weight.

Wheel-guides.

At the edges of the flooring of the bridge *wheel-guides* should be fixed consisting of baulks of timber varying from 6 inches to 1 foot high, according to the heaviness of the vehicles expected on the bridge. With a narrow roadway high wheel-guides should be used. The ends of the wheel-guides should not overlap, they should either butt or be halved into each other. In the pontoon equipment and in other bridges formed similarly these wheel-guides also serve to keep the flooring in position, and they are then termed *ribands.*

Handrails.

A bridge should generally be provided with *handrails* on both sides.

They should be about 3 feet above the roadway, and may consist of light spars or ropes fastened to uprights fixed to the points of support or to other portions of the bridge.

In the case of a bridge over a deep gap or over rushing water, screens of canvas or branches about 6 feet high should be fastened to the handrails to prevent animals crossing the bridge becoming frightened.

Camber.

Camber.

In order to allow for settlement in the connections of field bridges and to check progress on to a bridge as well as to facilitate exit from it, it is advisable to make the centre of a bridge higher than the ends, or in other words, to give *camber.*

The allowance to be made is obtained by giving a rise of 1 in 30 for about 30 feet from each end of a bridge where the banks are at the same level. In the case of a suspension bridge the rise should be continued up to the centre of the span.

Ruling Dimensions.

Width of roadway.

5. The width of roadway in the clear, *i.e.*, between the ribands, should be as follows :—

$1\frac{1}{2}$ feet to 3 feet for infantry in single file.

6 ,, minimum ,, { infantry in file. / cavalry in single file. / military carriages drawn over by hand.

8 ,, ,, ,, { infantry in fours. / cavalry in half sections. / military carriages, fully horsed.

9	feet	normal	for	infantry in fours. cavalry in half sections. military carriages, fully horsed.
10	,,	,,	,,	ditto, if mounted orderlies, &c., are required to return while the column is passing.
16	,,	,,	,,	double roadway for columns to pass one another.

Since parts of wagons project beyond the wheel tracks (Table B, p. 26) the width between handrails is usually a foot or two more than that of the roadway *in the clear*. For loaded camels the minimum width between handrails is 10 feet and for elephants 12 feet. Width between handrails.

When the bridge is narrow, wheel-guides should be fixed 5 feet 6 inches apart to assist in drawing guns, &c., over by hand.

The *headway* for ordinary military bridges should not be less than 9 feet for military wagons or for cavalry; and it should be increased to 11 feet for camels and to 15 feet for elephants. Headway.

SECTION III.—LOADS ON MILITARY BRIDGES AND STRESSES PRODUCED THEREBY.

The detailed design of military bridges.

1. After a decision has been reached as to the type of bridge to be used, the next question that arises is what are the necessary dimensions of its various members, so that they may be capable of supporting the loads that may come on them, without being unnecessarily strong.

For this purpose it is necessary to know—

i. The loads that may be brought to bear on the bridge and the effect of those loads.

ii. The strength of the various members of the bridge, taking into consideration not only the materials of which they are composed but also the form in which those materials are used.

The present section is devoted to the first of these considerations. The second will be dealt with in Sec. IV.

Calculations.

Calculations, in some form or other, are inevitable in this branch of military engineering. They may frequently be replaced by experience, but this experience itself is based on previous results obtained by their means.

Loads and their effect.

2. It is very important at the outset to note the difference between the actual loads on the bridge and the effect produced by those loads on the members of the bridge.

The load consists of certain weights that can be measured and expressed in units of weight such as pounds, hundredweights or tons.

The effect of these weights is to set up certain internal forces or stresses in the members of the bridge. These stresses can also be expressed in units of weight, but generally speaking the most important point about them is their intensity, that is to say, the number of units of weight per unit of area. The word "intensity" is commonly omitted, and the stresses are spoken of as so many pounds or tons per square inch, or tons per square foot, and so forth.

Classification of loads.

3. The loads that a military bridge may have to support are divisible into three classes :—

(1) The weight of the bridge itself.

(2) The weight of any material, not essential to the stability of the bridge, but introduced for convenience, such as sand spread to deaden the noise of animals' feet.

(3) The weight of the traffic, which may consist of men, horses, guns and wagons.

Live and dead loads.

4. An examination of the above loads shows that they fall under one of two heads :—

(1) Dead loads.

(2) Live loads.

This is a most important distinction, as weight for weight live loads bring a greater stress on the members of the bridge, owing to the vibrations and shocks set up by their sudden impact, and are consequently more injurious to the stability of the structure.

It is therefore usual in calculations to multiply the live loads by some factor, to convert them to what is called their "equivalent dead load." For field structures this factor is generally taken as 3 : 2. For example, that a ton of men moving across a bridge will bring as injurious an amount of stress upon the members of that bridge as a ton and a-half of some material, such as sand, lying quietly upon it.

When the load is liable to be applied very suddenly, as, for instance, to the planks of the roadway of bridges, and also in the case of certain loads moving rapidly, such as trains, or whose own moving parts may not be well balanced, such as traction engines, it is better practice to take this factor as 2.

5. Another point to be noted is the arrangement of the loads upon the bridge. The loads can be either— Distributed and concentrated loads.

(1) Distributed uniformly along its length, or a portion of its length.

(2) Concentrated at one or more places.

The meaning of this classification will be more apparent if it is considered how the various members of a bridge are influenced by the loads passing over it. The width of a wheel tyre or the width of a man's or animal's foot is small in comparison with the span of the chesses from one road-bearer to another. In this case it is better, therefore, to consider the load as a concentrated one. The load is transmitted to the road-bearers by the chesses, and thus, if the roadway of the bridge is covered with men, the load on the road-bearers is a distributed one, as every chess is loaded. If, however, a gun is passing over the bridge the wheels at any given moment are only supported by one chess, and the load on the road-bearers is a concentrated one. Finally, the load is transmitted to the transom by the road-bearers; and no matter how the latter are loaded, they are always distributed along the transom, and thus the load on the transom may be taken as a distributed one. Illustration.

6. It should be noted that the amounts of the loads to be carried by the bridge can be expressed in three different ways:— Modes of expressing loads.

(1) The actual total weight.

(2) The load per linear dimension of the bridge.

(3) The load per superficial dimension of bridge surface.

7. The numerical values of certain loads that may be expected on military bridges must now be considered. It will be convenient to take them in the order of the original classification. Numerical values.

In calculating the dimensions of a member of a bridge it is necessary to take into account the weights of any other members Superstructure.

that it supports in addition to its own weight. To do this, an estimate of the weight must be made from the actual sizes of material that previous experience shows likely to be necessary. It is not sufficient to allow so much per foot run to cover this weight.

In the case of timber bridges, the weight of square scantlings can easily be worked out. For tapering spars of round section, the chart given in Pl. XV can be referred to.

An approximate rule for the cubic contents of a round spar is as follows :—

$$\text{Cubic contents} = \frac{L}{4}(D^2 + Dd + d^2)$$

Where L is the length of the spar, and D and d the diameters of the two ends.

The weight of superstructure will always be a dead load, and, in the majority of cases, distributed also.

Roadway coverings. The load brought on bridges by any covering on the roadway will depend on the material used and its depth, and will always be a dead, and also a distributed, load.

Traffic loads. The following paragraphs and tables give the maximum weights that can be brought on a bridge by the passage of troops and vehicles of various kinds :—

These loads are all live loads. Whether they should be treated as distributed or concentrated depends on their distance apart compared to the length of the bridge member under calculation. In general, however, infantry and cavalry are treated as distributed and guns and vehicles as a succession of concentrated loads. In the case of guns and vehicles it may be necessary to consider the weight of the horses by which they are drawn and also those of the gun or vehicle immediately behind them.

Infantry. The weight of infantry in marching order, assuming they are crowded at a check to the greatest extent possible, short of losing their formation, can be taken as follows :—

Single file ...	... 140 lbs., or	$1\frac{1}{4}$	cwts. per foot run.
File ...	... 280 ,,	$2\frac{1}{2}$	,,
Fours ...	... 560 ,,	5	,,

Infantry in marching order average 200 lbs. per man.
,, unarmed ,, 160 ,, ,,

When infantry lose their formation and crowd together in a disorganized mass they may bring the following weight on the bridge surface :—

In marching order	133 lbs. per square foot.
When unarmed	175 ,, ,, ,,

Cavalry. The weight of cavalry in marching order can be taken as follows :—

Single file ...	... 200 lbs., or	$1\frac{3}{4}$	cwts. per foot run.
Half sections	... 400 ,, ,,	$3\frac{1}{2}$	,, ,, ,,

A cavalryman and his horse in marching order average about 1,400 lbs. About three-fifths of this is borne on the fore legs. It must therefore be assumed that a weight of about 850 lbs. can be brought on to one foot of a cavalryman's horse.

Cavalry in a disorganized mass weigh about 120 lbs. per square foot.

The weights brought on bridges by various animals, intended for draught, pack and commissariat purposes, are shown in Table A (p. 25). Animals.

The weights of guns and other vehicles are given in Table B (p. 26). Unless otherwise stated, it is assumed that they are loaded to their maximum capacity. Guns and vehicles.

8. In considering the effects of the various loads on the bridge members, a distinction must be made between— Effect of loads.

(*a*) The stresses, that is the forces set up in these members by the loads.

(*b*) The strain, that is the effect of the stresses on the materials of the member, which always consists of some kind of deformation.

Up to a certain limit this deformation is temporary, and disappears when the load is removed. Above this limit part of it becomes permanent, and the failure of the material is the final result.

9. There are three kinds of simple stress :— Stresses and strains.

(1) *Tension or pulling.*—The loads act outwards along the axis of the piece of material, giving rise to a tensile stress on any cross-section normal to the axis. The corresponding strain is an extension of the material.

(2) *Compression or thrusting.*—The line of action of the loads is the same as for tension, but they tend towards, instead of away from, each other, giving rise to a stress that compels the particles into closer union. The corresponding strain is a shortening of the material.

(3) *Simple shear.*—The loads act parallel to each other in opposite directions, tending to cause the two portions of the material to slide one upon the other. The corresponding strain is a distortion of the material. Torsion is the particular case of shear stress that occurs when a piece of material is twisted. The effect is to cause any two adjacent normal sections to revolve relatively to one another. The strain in this case is measured by the angle of rotation of one end of the material with respect to the other.

These three simple stresses may be combined with one another to form compound stresses :—

(4) *Bending or transverse stress.*—The load is applied in such a way that it causes a piece of material to bend. Here

the bending action of the load results in a curving of the beam, the material on the convex side being lengthened and put into tension; that on the concave side is put into compression. Shearing stresses are also set up. The corresponding strain is a deflection, measured by its amount in a direction at right angles to the axis.

(5) *Buckling stress.*—The load is applied inwards along the axis of the piece of material, whose dimension in this direction is long in comparison with its cross-section, thus causing the bar to bend sideways. The corresponding strain is lateral deflection.

Measurement of stress intensity.

10. In the case of simple stresses their intensity is measured by the number of units of force per unit of area. Compound stresses must be analyzed into their component simple stresses, and the intensity of these measured in the same way.

Uniform stresses.

11. When the load acts in such a way that the intensity of stress is the same at all points of the sectional area considered, it is said to be uniform. In such a case the intensity of stress is—

$$f = \frac{P}{A}$$

Where P is the total force, A the area of the section considered, and f the intensity of the stress. This applies to simple tension, compression and shear.

Eccentric loads.

12. The load may be applied in such a way that the intensity of the stress is not the same at all points of the area. For instance, if the pull in a tie bar is applied in a line that lies outside the geometrical axis of the bar, the intensity of the tension on a section at right angles to the axis is not the same at all points. In such a case the foregoing equation only serves to give the average intensity of stress.

In field structures the tension members are usually such that the load is applied to them symmetrically; but in the case of compression members the load is, as often as not, applied eccentrically, as for example, the legs of a lashed spar trestle.

When the amount of the eccentricity of the loading is known, its effect on the distribution of stress intensity can be seen from Table C (p. 30). The sections considered are solid round and rectangular only. The first column shows the amount of the eccentricity, that is, the ratio of the distance from the centre of the section to the point of application of the load, to the diameter of the circle, or the side of the rectangle (parallel to the displacement) respectively. The second and third columns show the percentage excess of the maximum over the mean stress in round and rectangular sections respectively.

This table shows the necessity of designing structures so that the stresses may be as uniform as possible, as it is the maximum intensity of stress that determines its ultimate strength.

13. Members of field structures subjected to transverse stress can be grouped as follows :— Transverse stress.

(1) *Cantilevers.*—Fixed at one end, unsupported at the other.
(2) *Beams.*—Supported at each end.
(3) ,, Fixed at one end, supported at the other.
(4) ,, Fixed at each end.

Field structures, as a rule, are not concerned with the two latter groups. Generally speaking the effect of a load on a fixed beam has not so great a maximum as when acting on a beam that is supported only, and as it is difficult to ensure thorough fixation, it is generally more conservative practice to treat all beams in field structures as supported only.

The effect of a load applied so as to cause transverse stress on a piece of material is to cause, at any ideal section, a tendency for the one portion to rotate relatively to the other, in addition to certain shearing forces. This tendency is resisted by the stresses of tension and compression set up across that section. As no rotation takes place, the moment of these stresses must be equal to the bending moment produced by the external forces.

In field structures it is not, as a rule, necessary to consider the shearing force exerted upon a beam transversely loaded. As will be seen, when the strength of materials is considered, the solid sections usually employed, if capable of withstanding the transverse stress, will be more than sufficient to stand the shear.

14. The bending moment at any section of a piece of material transversely loaded, due to the external forces, is the algebraic sum of the moments of the forces on either side of that section, that is to say, of the reaction at either support and the loads between that support and the section in question. Bending moment.

The bending moment at any section is usually denoted by the symbol, M_f.

In field structures the cross-section of the members under transverse stress is, almost without exception, practically invariable. It is sufficient, therefore, to know the value of the bending moment at the section where it is a maximum. This value is generally represented by the symbol M_{ff}. Its value and position in the cases that commonly arise in practice are as shown in Table D (p. 30) (Pl. IX). Maximum moment.

In other cases, such as two or more concentrated loads, or a distributed load over a portion of the span only, the value and position of the M_{ff} must be worked out by finding the M_f at any section, and finding the position of the section giving the maximum value by some suitable method.

It has been assumed so far that the cantilever or beam is loaded in some definite manner with one or more concentrated or distributed loads. In the case of certain members the total load consists of a series of component loads, as a rule kept at fixed Moving loads.

distances apart, crossing the structure, as, for instance, a team or horses drawing a limber and gun behind them. At any given instant the position of all these various loads is known, and the value and position of the M_{ff} can be found. But this value and position are constantly changing as the total arrangement of loads passes across the structure. It is therefore necessary to find out the value and position of the greatest value of the M_{ff}, or the M_{fff} as it is written.

In the more simple field structures its position is not of much importance, as it has been stated before that the section of the member can be considered invariable. In the case of girder bridges its position is of importance.

When the load is taken as distributed the maximum bending moment occurs when the whole span is loaded, and this case therefore falls under the rules already given.

In military bridges, where such members as a rule are not very long, it is usual to treat the load of a column of infantry or cavalry as a distributed load, but to deal with guns or vehicles as a series of concentrated loads.

The case of a series of concentrated loads will only be considered as regards supported beams, as such an arrangement of loads is obviously not likely to be directly moving along a cantilever, and fixed beams are excluded for the reasons already given.

One load.

When there is one concentrated load moving across a span, the M_{fff} occurs under that load when it arrives at the centre of the span. Its value can then be found by the previous rules.

Two loads.

The case of two concentrated loads can be stated as follows :— When the ratio K of the distance apart of the loads to the span exceeds the value $R + 1 - \sqrt{R^2 + R}$ where R is the ratio of the heavier to the other load, the M_{fff} will occur under the heavier load when it arrives at the centre of the span. The value of K varies from nearly ·59 when the two loads are equal to ·50 when one is infinitely greater than the other ; it will be seen therefore that in all cases the other weight will be off the span when the heavier is at the centre, and thus the value of the M_{fff} can be found by the previous rules. The determination of this critical value for the span can be read from Pl. IV.

In other cases the M_{fff} will occur under the heavier load when it and the centre of gravity of the two loads are at equal distances from the respective supports. The position of the loads being known, its value can be worked out by the usual rules, or can be taken from the following expression :—

$$M_{fff} = \frac{\text{Sum of the loads}}{\text{span}} \left\{ \begin{matrix} \text{distance of heavier load} \\ \text{from nearer support} \end{matrix} \right\}^2$$

Three or more loads.

When the series consists of three or more concentrated loads it is not possible to give such a simple solution as when there are only two. It does not necessarily happen that the M_{fff} will

occur under the heaviest load, though it must be under some load. The problem entirely depends on the mutual proportions of the several loads and their respective distances apart, but the general case of n loads on a supported beam is given on p. 24.

Results.

The M_{fff} produced on the road-bearers of bridges whose spans vary from 4 feet to 30 feet, by those combinations of moving loads that might more commonly be met with on military bridges, and that are likely to have a predominating influence on the size of the road-bearers, are given in Pls. V, VI, VII and VIII. In these results the average loads produced by horses of the stamp employed have been taken into account, and it has been assumed in every case that a gun or vehicle is followed as closely as possible by the horses of other vehicles. The live loads produced by these various vehicles are converted to equivalent dead loads by multiplication by the factor 3:2, except in the case of the traction engines and lorries, where this factor is taken as 2, to allow for a possible want of balance of the moving parts. All wagons have been assumed to be loaded to their maximum capacity, and in all cases the additional bending moment produced by an appropriate roadway has also been calculated and added to the result shown.

Equivalent distributed load.

In railway bridges, altnough the weight of the locomotive and train is brought on to the span as a series of concentrated loads, it is frequently assumed, for purposes of calculation, that the total load is equivalent to a distributed load over the whole span. The value of this distributed load depends on the length of the span and the weight of the locomotive, but the amounts that would cover the heaviest locomotives to be found on any standard lines in this country are given in Sec. XIII of Part IIIB.

Units.

15. It is very important in all calculations of the bending moment to see that the same units are used from beginning to end. Thus, if W is in pounds and L in feet, the bending moment will be in foot-pounds; while if W is in tons and L in inches, the moment will be in inch-tons.

A very common unit for the moment is in inch-pounds. In this case a distributed load given as so many pounds per foot run must be reduced to pounds per inch run before the moment can be expressed in these units. For instance, the M_{ff} produced by a superstructure weighing 80 lbs. per foot run over a 10 feet 6 inches span of a supported beam is not $\left(\text{substituting in } \frac{wL^2}{8}\right)$

$$\frac{80 \times (126)^2}{8} \text{ inch-lbs.}$$

but is

$$\frac{\frac{80}{12} \times (126)^2}{8} \text{ inch-lbs.}$$

16. It is to be noticed that the bending moments depend upon the arrangement of the total load and upon the length of the span, but that they are not dependent in any way upon the material of the beam.

It should also be noticed that a single concentrated load at the centre of a supported beam brings exactly twice the M_{ff} upon that beam, as the same total load uniformly distributed over the span. Great care must be taken not to make any confusion between these facts, the reason for which will be obvious if the methods for calculating the respective bending moments are inspected, and the arbitrary allowance made to convert a live load into an equivalent dead load.

Graphical methods.

17. The stresses produced in the various members of a structure can often be obtained conveniently by graphical methods. These graphical determinations are based on the principle of the parallelogram of forces, and its corollary the polygon of forces.

Illustrations.

A few simple illustrations are as follows :—

(*a*) In order to determine the stress on the leading block of a derrick heeled over at 3 : 1 and raising a given weight, draw a line diagram of the derrick at the proper slope (Pl. XI, Fig. 1). If ABC represents the fall passing through the leading block at B, the tension in the lashing is caused by the tensions in AB and BC. These will not be equal, owing to the friction in the leading block, but instead AB will be somewhat the smaller.

The actual stresses may be calculated by the formula on page 92. These values are laid off at a convenient scale along AB and BC. Then, if the parallelogram ABCD be completed, the line BD will give the stress in the snatch block lashing at the same scale as regards magnitude and also in direction.

Fig. 2 shows how the stress is increased when the running end of the fall is carried in the direction of heel.

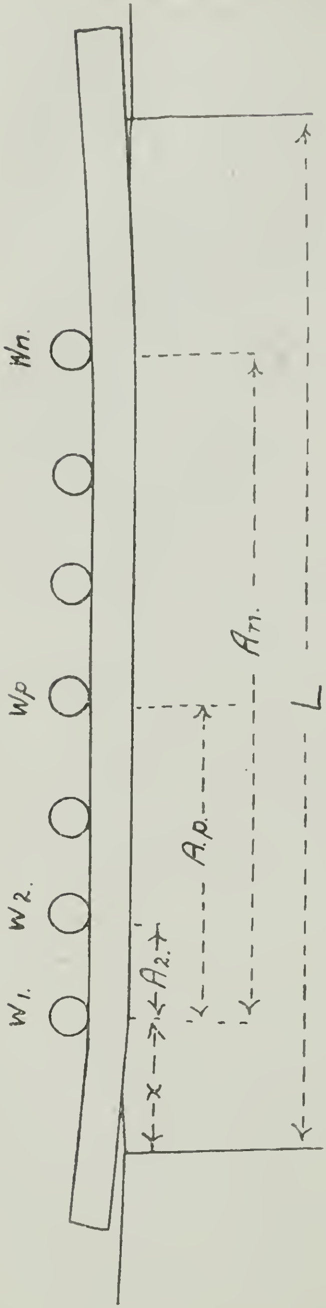
(*b*) In Fig. 3 AB represents the side elevation of sheers at a heel of $\frac{3}{1}$, and AC the back guy, drawn at the proper slope. From A drop a perpendicular AW, and make AD, at any convenient scale, represent the weight lifted; complete the parallelogram ADFE. Then AE, measured at the same scale, represents the tension in the back guy, and AF represents the thrust in the sheers due to the weight. Fig. 4 shows a front elevation of the sheers. From A draw AF vertically downwards, making it equal to the distance AF obtained in Fig. 3; complete the parallelogram AHFG. Then AH and AG represent the thrust in the respective legs, due to the weight.

(*c*) Fig. 5 shows a line diagram to scale of the side elevation of a tension bridge without struts. AB is the back tie, BC the vertical frame, D, E, F, the transoms, and T_1, T_2, T_3, the ties. Calculate the maximum load on each transom, including superstructure, and divide by two, as each transom is supported by two ties. Draw lines vertically downwards from D and E and upwards from F. On these lines lay off the loads found as above, and complete the respective parallelograms, which then give the tension in each tie and the compression in the outer road-bearers. It must be noticed that the tension found in the road-bearers DE must be added to that found in CD, to give the total compressive stress in CD. Fig. 6 shows the respective tensions in the ties laid off along the lines representing these members from B. From the end of the line representing the tension in T_1, draw t_2 parallel to T_2 and equal to the tension in that tie, and similarly from the end of this line for the tension in T_3. If B be joined to the end of this last line it will represent the resultant of all the tensions in direction and magnitude. To ensure a direct vertical thrust on BC the angle ABC should equal the angle RBC. If this be the case, and BG be made equal to BR, the diagonal of the parallelogram RBGH will give the thrust in each leg.

(*d*) Fig. 7 shows how an oblique stress can be resolved into one component acting transversely to the axis of the beam, and another in the direction of its length.

Graphical methods of a similar nature can be employed to find the stresses in the various members of a girder.

General Case of n *Loads on a Supported Beam.*



Let W_1, $W_2 \ldots\ldots W_p \ldots\ldots W_n$ be the n loads, and let A_1, $A_2 \ldots\ldots A_p \ldots\ldots A_n$ be the respective distances of the loads from, say, the left hand load; A_1 is, of course, equal to zero. Let x be the distance of the left hand load from the left hand support, and let L be the length of the span, as in figure below.

Then the bending moment under the p^{th} load, W_p, will be greatest when

$$x = \frac{1}{2}\left\{L - \frac{\Sigma_1^n WA}{\Sigma_1^n W} - A_p\right\}$$

and will then be

$$\frac{\Sigma_1^n W}{4L}\left\{L - \frac{\Sigma_1^n WA}{\Sigma_1^n W} + A_p\right\}$$

$$+ \Sigma_1^{p-1} WA - A_p \Sigma_1^{p-1} W$$

To use these formulæ, select some load, usually the greatest, and some appropriate portion of the series. Calculate the position giving the M_{fff} and inspect it to see that none of the loads in the selected position are off the span, and that none, not in the selected portion, are on it. If either of these prove to be the case, the selected portion must be amended. Then calculate the value of the M_{fff}. This determination must be made for as many selected loads and portions of the series as may be necessary, and the greatest value of the M_{fff} finally chosen.

TABLE A.—BRIDGE LOADS DUE TO ANIMALS.

Purpose.	Description.	Weight in lbs.					Area occupied on bridge.		Weight per square foot.	Distances.		
		Of animal.	Of load.	Total.	On hind legs.	On fore legs.*	Dimensions.	Square feet.		From front axle to hind legs.	From hind legs to fore legs.	From front legs to hind legs of animal in front.
Draught.	Light horses ...	1,200	...	...	480	720	...	...	...	4′ 6″	4′ 0″	4′ 0″
	Artillery horses ...	1,400	...	...	560	840	...	...	...	4′ 6″	4′ 0″	4′ 0″
	Farm horses ...	1,700	...	...	680	1,020	...	...	...	4′ 6″	4′ 0″	4′ 0″
	Shire horses ...	2,000	...	...	800	1,200	...	...	...	4′ 6″	4′ 0″	4′ 0″
	15-hand mules ...	1,000	...	...	400	600	...	...	...	4′ 6″	4′ 0″	4′ 0″
	Oxen	...	...	...	...	...	...	...	...	...	...	...
	Elephants ...	7,500	...	...	3,000	4,500	11′ × 5′	55	82	5′ 6″	6′ 6″	10′ 6″
Pack.	Horses	1,400	200	1,600	640	960	...	...	...	...	...	...
	Mules	1,000	160	1,160	460	700	...	...	...	...	...	...
	Indian bullocks ...	450	150	600	200	400	5′ × 2′9″	13·5	41	...	3′ 6″	...
	Elephants ...	7,000	1,500	8,500	3,500	5,000	11′ × 9′	100	85	...	6′ 6″	...
	Camels	1,200	400	1,600	600	1,000	10′ × 7′	70	23	...	4′ 6″	...
Commissariat.	Cattle	1,000	...	...	...	...	...	10	100	...	...	...

* This may be taken as the greatest weight that can be brought on to any one foot.

TABLE B.—BRIDGE LOADS, &c., DUE TO GUNS AND VEHICLES.

Description of vehicle.	Weight in lbs. With full load, including men. Fore or limber wheels.	Weight in lbs. With full load, including men. Hind or gun wheels.	Distances. Front axle to hind legs of horse.	Distances. Axle to axle.	Distances. Hind axle to fore legs of horses following.	Wheel track out to out.	Width of tyre.	Greatest projection beyond track.
VEHICLES COMMON TO ALL ARMS.								
Wagon, General Service, Mark IV ...	3,250	2,360	4′ 6″	6′ 1″	6′ 0″	5′ 3″	$2\frac{1}{2}$″	5″
„ „ Mark VIII ...	3,050	2,400	4′ 6″	7′ 6″	6′ 0″	5′ 3″	$2\frac{1}{2}$″	5″
„ „ Mark X	3,050	2,300	4′ 6″	7′ 1″	6′ 0″	5′ 3″	$2\frac{1}{2}$″	6″
ARTILLERY VEHICLES.								
Gun and carriage, field, Q.F. 13-pr., Mark I, with limber	1,920	2,570	4′ 6″	9′ $11\frac{1}{2}$″	6′ 6″	5′ 3″	3″	6″
Wagon, ammunition, Q.F. 13-pr., Marks I and II, with limber	2,210	2,030	4′ 6″	7′ $3\frac{1}{2}$″	5′ 0″	5 3″	3″	6″
Gun and carriage, field, Q.F. 18-pr., Mark I, with limber	2,200	3,100	4′ 6″	9′ 11″	8′ 0″	5′ 3″	3″	6″
Wagon, ammunition, Q.F. 18 pr., Marks I and II, with limber	2,580	2,340	4′ 6″	7′ $4\frac{3}{4}$″	5′ 0″	5′ 3″	3″	6″

Howitzer and carriage, field, B.L. 5″, Mark I, with limber, Mark I	3,100	2,920	4′ 6″	8′ 2½″	5′ 0″	5′ 2″	3″	6″
Ditto, carriage, Mark I, with limber, Mark II	2,730	2,920						
Wagon, ammunition, B.L. 5″ howitzer, Mark I, with limber, Mark I	3,130	2,860	4′ 6″	7′ 2¾″	5′ 0″	5′ 2″	3″	6″
Ditto, wagon, Mark II, with limber, Mark II	2,710	3,560						
Gun and carriage, field, B.L. 60 pr., Mark I, with limber, Mark I. Gun in travelling position	4,680	7,460	4′ 6″	13′ 11″	8′ 0″	5′ 2″	6″	11″ outriggers folded 2′ 3½″ outrigging extended
Ditto. Gun in firing position	2,440	9,830	4′ 6″	13′ 11″	12′ 6″			
Wagon, ammunition, B.L. 60-pr., with limber	2,560	3,630	4′ 6″	7′ 2½″	5′ 0″	5′ 2½″	3″	6″
Howitzer and carriage, siege, B.L. 6″, 30-cwt., with limber	2,100	7,820	4 6″	8′ 5″	8′ 0″	5′ 2″	4″ carriage 3″ limber	9″
Gun and carriage, field, Q.F. 15-pr., Mark I, converted to long recoil with limber	2,280	3,200	4′ 6″	9′ 5″	7′ 6″	5′ 2″	3″	6″
Wagon, ammunition, Q.F. 15-pr., converted to long recoil with limber	2,250	2,690	4′ 6″	7′ 5″	5′ 0″	5′ 2″	3″	6″
Gun and carriage, travelling, Q.F. 4·7″, with limber, Mark I	1,950	8,380	4′ 6″	9′ 1½″	14′ 6″	5′ 2″	6″ carriage 3″ limber	9¼″
Gun and carriage, travelling, Q.F. 4·7″, converted Mark I, with limber, converted Mark I	2,630	9,200	4′ 6″	10′ 4½″	14′ 6″	5′ 2″	6″ carriage 3″ limber	9′

TABLE B.—BRIDGE LOADS, &c., DUE TO GUNS AND VEHICLES—*continued.*

Description of vehicle.	Weight in lbs. With full load, including men. Fore or limber wheels.	Hind or gun wheels.	Distances. Front axle to hind legs of horse.	Axle to axle.	Hind axle to fore legs of horses following.	Wheel track out to out.	Width of tyre.	Greatest projection beyond track.
ENGINEER VEHICLES.								
Cart, tool, double, R.E.	2,600	2,600	4′ 6″	8′ 9″	5′ 0″	5′ 5″	$2\frac{1}{2}$″	$4\frac{3}{4}$″ each side.
Wagons, pontoon	2,200	3,800	4′ 6″	10′ 5″		5′ 8″	3″	$5\frac{1}{4}$″ ,,
Wagons, trestle	2,300	3,700	4′ 6″	10′ 5″		5′ 8″	3″	$5\frac{1}{4}$″ ,,
Wagons, spring, Field Troop, R.E. ...	1,170	1,630	4′ 6″	7′ 1″	5′ 0″	5′ $5\frac{1}{2}$″	3″	5″ ,,
Wagons, cable	1,220	2,440	4′ 6″	8′ 4″	6′ 0″	5′ $3\frac{1}{2}$″	3″	$5\frac{1}{2}$″ ,,
Wagons, air-line, 6-horsed...	3,380	4,120	4′ 6″	9′ 3″	6′ 0″	5′ 2″	3″	11″ ,,
Ditto 4-horsed...	2,250	2,750	4′ 6″			5′ 2″	3″	11″ ,,
Wagon, light spring, R.E....	900	1,350	4′ 6″	6′ 0″	5′ 0″	5′ 7″	$2\frac{1}{2}$″	$4\frac{1}{2}$″ ,,
Wagon, special, Wireless Company ...	2,070	2,730	4′ 6″	7′ 6″	5′ 0″	5′ 4″	3″	11″ ,,
Wagons, boat, Field Troop, R.E.	1,660	2,320	4′ 6″	7′ 0″	5′ 0″	5′ 6″	$2\frac{1}{2}$″	5″ ,,
Wagon, reservoir, gas	1,780	2,670	4′ 6″	5′ 2″	5′ 0″		$2\frac{1}{2}$″	
MEDICAL VEHICLES.								
Wagons, ambulance...	2,020	2,820	4′ 6″	7′ $3\frac{1}{2}$″	5′ 0″	5′ 2″	$2\frac{1}{2}$″	5″ ,,
Wagons, ambulance, light								

MISCELLANEOUS.									
Wagon, bread and meat	3,120	4,680	4′ 6″	6′ 6″	5′ 0″	5′ 7″	2½″	4½″	,,
Wagon, printing	1,860	2,610	4′ 6″	6′ 3″	5′ 0″	5′ 5″	3″	4½″	,,
HIRED TRANSPORT.									
Wagons, 4-horsed, Auxiliary Transport Company	2,150	3,000	4′ 6″	5′ 0″	5′ 0″				
Carts, 2-horsed, Auxiliary Transport Company	...	2,500	4′ 6″	...	5′ 0″	5′ 6″	3″	4½″	,,
Heavy farm wains	4,800	4,800	4′ 6″	5′ 6″	6′ 0″	5′ 5″	2¼″	6½″	,,
Large delivery vans...	5,000	7,000	4′ 0″	5′ 6″	7′ 0″	5′ 7½″	2″	4½″	,,
MOTOR VEHICLES.									
Two-seated motor car	1,000	1,350	...	7′ 10″	...	4′ 5″	3″	8″	,,
Heavy touring motor car	2,500	4,200	...	11′ 0″	...	5′ 4″	4″	4″	,,
30 cwt. A.S.C. lorry (petrol) or motor ambulance	4,000	7,900	...	11′ 6″	...	6′ 5″	9½″*	2″	,,
3 ton A.S.C. lorry (petrol)	4,550	10,950	...	13′ 7″	...	6′ 5″	11″*	2″	,,
Light steam tractor (one-truck engine) ...	4,500	10,000	...	8′ 0″	...	5′ 10″	1′ 0″	2″	,,
Medium steam tractor (two-truck engine)	10,600	21,000	...	9′ 11″	...	7 0″	1′ 4″		
Heavy steam tractor (three-truck engine)	11,200	24,700	...	11′ 1″	...	7′ 5″	1′ 4″		
Mobile workshop truck	9,000	9,000	...	10′ 2″	...	5′ 11″	9½″	9½″	,,
5-ton truck	8,400	8,400	...	8′ 7″	...	5′ 5″	8½″	8″	,,
Thorneycroft lorry	6,000	12,000	...	10′ 6″	...	6′ 7″	11″		
Trailer for ditto	4,400	4,400	...	8′ 10″	...	6′ 4″	4½″	3½″	,,
Heavy commercial lorry	7,100	17,700	...	13′ 0″	...	6′ 8½″	8″		

* These are twin tyres, rubber. Actual width of tyre in contact with roadway is 4″ to 6″ according to age of tyres.

TABLE C.—EFFECT OF ECCENTRIC LOADING.

Ratio of displacement.	Percentage excess of maximum stress over average stress intensity.		Remarks.
	Round section.	Rectangular section.	
0	0	0	At centre.
0·05	40	30	
0·1	80	60	
0·2	160	120	
0·3	240	180	
0·4	320	240	
0·5	400	300	At circumference or edge.

TABLE D.—MAXIMUM BENDING MOMENT.

Member.	How loaded.	Value of M_{ff}.	Position of M_{ff}.
Cantilever ...	Concentrated load at end	WL	At point of fixing.
Ditto ...	Distributed load	$\frac{WL}{2} = \frac{wL^2}{2}$	Ditto.
Supported beam...	Concentrated load at centre	$\frac{WL}{4}$	At centre.
Ditto ...	Distributed load	$\frac{WL}{8} = \frac{wL^2}{8}$	Ditto.

The length of the cantilever or beam is taken as L and the total load as W.

In the case of distributed loads $W = wL$, where w is the load per unit of length.

SECTION IV.—MATERIALS.

1. The stresses produced in a piece of material by the external loads acting upon it must be exactly balanced, up to the point where failure occurs, by stresses due to the alteration in the mutual arrangement of the particles of the material. These stresses must balance one another, not only in their total amounts but also in their intensities at any point. The visible effect of this alteration in the material is known as the strain, referred to in para. **9,** Sec. III. Up to the elastic limit of the material the strain is proportional to the stress. Beyond this limit this relation ceases to be true, the strain of the material becomes partially permanent, and if the stress is further increased failure ensues. Balance of external and internal stresses.

If more than a certain amount of stress intensity is applied to any piece of material, that material will fail in a manner dependent upon the nature of the stress and the material. For the same material, and the same form of stress, this intensity will have approximately the same value. Such intensity is called the breaking stress for the material in question. It is obviously undesirable to load structures until the stresses in their members approach this limit. In fact, the stresses should be kept so low that the strain in the material does not become of a permanent nature—in other words, the strain should be kept below the elastic limit. To ensure this, and also to allow for variations in the properties of any particular piece of material, the stress to which it is subjected should only be a fraction of the average breaking stress of the material under consideration. Breaking stresses.

2. This ratio of the breaking or ultimate stress to the working stress that it is proposed to employ is called the factor of safety. The general principle adopted, therefore, in calculating the strength of materials for field structures, is as follows:— The average stress that causes the material under discussion to fail, whether tension, compression or shear, is known either from tabulated results or by direct experiment. Some fraction of this is adopted as the limit up to which it is thought the material may be stressed with safety. The total stress that will be brought on the material by the proposed loading is then calculated, and the dimensions of the piece of material so chosen that the maximum intensity of the stress shall not exceed this limit. The value to be given to this factor of safety depends upon— Factor of safety.

- (*a*) The permanence of the work. For hasty field structures it is allowable to use a smaller factor than for more permanent work.
- (*b*) The liability of the material, as regards any particular portion, to differ from the average, in its elastic limit and ultimate strength. For materials with a large possible range of strength the factor of safety, which operates on the average, must necessarily be greater

(c) The ratio of the stress intensity that produces a permanent set in any given material to the intensity that causes failure.

(d) The nature of the stresses, whether constant, variable or alternating, simple or compound. The ultimate limit for alternating stresses is about 30 per cent. or 40 per cent. of the ultimate statical limit. Thus if a factor of safety of 3 is considered sufficient for a steady load, a factor of 8 or 9 would be required for an alternating stress.

(e) The possibility of a diminution of section by corrosion.

(f) The skill of the workmen who will be employed in the construction.

The value of the factor of safety should never be less than those given below, and should always be increased if the material is not absolutely sound or if, as in a bridge, it is subjected to stresses which are frequently recurrent or applied for a considerable period, or if the material is used under any other unfavourable conditions :—

Unselected wood (dry)	3
Selected wood (dry)	2
Cast iron	3
Wrought iron	2
Steel	2
Rope (hemp or wire)	3

Tension members.

3. When the forces acting on the members of a structure are such as to produce a stress of tension, the dimensions of those members can be very easily calculated. The working stress of the material having been decided upon, the dimensions of the member can be so chosen as to keep the intensity below that limit, due allowance being made if necessary for any eccentricity of loading (para. **12**, Sec. III). It is to be noted that the stress intensity is not affected by the length of a tension member.

Expression of stress intensities.

Sometimes, when the tension member is in the form of a thin sheet, such as a strip of canvas or a plank of small thickness, it may be more convenient to express the stress intensity in units of weight per unit of width. It must be understood that the intensity is in reality dependent on the area of the cross-section, as in all other stress intensities ; but when the thickness is small and uniform, the above convention is often simpler for purposes of calculation. Sometimes, when the member is of circular section, it is more convenient to express the stress intensity in terms of the square of a linear dimension as the circumference in the case of ropes, and in the case of chain the diameter of the metal it is composed of.

Compression members.

4. The calculations required in the case of compression members are not so simple as those for tension members. The length of

the members influences their strength to a very large degree. Assuming, to begin with, that the line of the load is in the geometric axis of the member, the intensity of stress over a section at right angles to the direction of the thrust will be uniform as long as the member remains in a straight line. If the column is short in proportion to its smallest dimension, failure takes place by direct crushing. But in what is called a long column failure takes place partly by crushing and partly by bending. As soon as bending begins the distribution of stress intensity is no longer uniform. If the line of the load is not in the line of the geometric axis of the member, the distribution of stress intensity is not uniform from the beginning, and bending takes place more readily.

Long and short columns. It is not possible to draw a hard and fast line between long and short columns; it depends to a great extent upon the material. As a rough rule the ratio of length to least dimension should not exceed 8 to 1 if the column is to be treated as a short one. In the case of a column of non-uniform section—a tapering spar, for example—the least dimension to be taken for purposes of calculation is that of its middle section, for it is at this section that the maximum stress intensity will occur.

Round and fixed ends. The strength of a column also depends upon the way in which its ends are secured. If they are free to turn they are said to be "round," and if they are not able to rotate they are said to be "flat" or "fixed." A column with fixed ends is as strong as one of the same least dimension and half its length, and if one end is fixed, as strong as one two-thirds its length. Before any extra strength can be assumed on this account it is necessary to be sure that the fixing is very thorough, and that no rotation is possible in any direction if the cross dimensions of the section are about equal, or that no rotation is possible in the plane containing the least dimension if this is decidedly less than the other dimension of the cross-section.

Rough rule. A rough rule to allow for this diminution of strength as the ratio of length to least dimension increases, is given below. In this rule, the allowable safe stress becomes less as this ratio increases. If r is taken as the safe compression in lbs. per square inch—for example, on a short column in which there is no danger of buckling—L the length of the column and d the least dimension, in the same units as L, then, the ends being considered round—

When L is not greater than	$8\,d$,			safe stress is		r.
,, L is between	$8\,d$	and	$12\,d$	,,	,,	$5/6\,r$.
,, L ,,	$12\,d$	,,	$24\,d$	,,	,,	$1/2\,r$.
,, L ,,	$24\,d$	,,	$36\,d$	,,	,,	$1/4\,r$.
,, L ,,	$36\,d$	,,	$48\,d$	,,	,,	$1/6\,r$.

Example. A pile, 12 feet high out of the ground, and 5 inches by 5 inches in cross-section, has to support a load of 7,000 lbs. From the

nature of the construction one end can be considered as fixed, the other must be supposed free to move. The pile is thus equivalent as regards strength to a column with both ends rounded 8 feet long. The least dimension is 5 inches, giving a ratio of about 19. Assume the pile to be of Baltic fir, with an ultimate crushing strength of, say, 6,000 lbs. per square inch. Using a factor of safety of 4, the value of *r* on a short column would be 1,500 lbs. per square inch. With the given ratio the stress intensity can be $\frac{1}{2} \times 1{,}500$, or 750 lbs. per square inch (this is, of course, the average intensity). The area of the cross-section is 25 square inches, giving a total allowable stress of 18,750 lbs., so that the pile is amply strong enough.

Gordon's formula.

A formula that gives more satisfactory results than the foregoing rough rules is Gordon's, as long as the columns to which it is applied are round or rectangular wooden beams—

$$P = \frac{r \cdot A}{1 + a\left(\frac{L}{d}\right)^2}$$

where P is the total working load on the column, A the area of the column, *r* the safe intensity of stress on a short column (in the same units as P and A combined), L the length of the column, *d* its least dimension (in the same units as L), and *a* an empirical coefficient, given in the following table :—

Type of column.	Ends flat or fixed.	Ends round or hinged.	One end round, the other fixed.
Solid round	$\frac{1}{190}$	$\frac{1}{48}$	$\frac{1}{108}$
Solid rectangular ...	$\frac{1}{250}$	$\frac{1}{62}$	$\frac{1}{140}$

Graphical charts.

From the foregoing formula six graphical charts have been worked out, covering the majority of cases of timber columns likely to be met with in field structures (Pls. XII, XIII and XIV). The use of these charts will obviate the necessity of any calculations, except the alteration in the value of *r*, when timber other than Baltic fir is used, or an adjustment in the equivalent length of the column, when the ends are not secured in the manner indicated in the charts. It will be noticed that in the chart for round spars the safe stress has been taken lower than for rectangular beams. This is to allow for eccentric loading, which is more likely to occur with the former. Should eccentric loading take place with the latter, a similar allowance must be made.

Example.

The upright of a trestle in a railway bridge has to stand a thrust of 30 tons. Its unsupported length is 11 feet. Find the size of square baulk required. Taking the chart for square baulks and following the horizontal line representing an un-

supported length of 11 feet, it will be seen that the curve representing 30 tons is cut at a point that carried downwards shows that a baulk about 12 inches square will be required.

5. A very important case of compressive stresses in field structures is bearing stress. The stress exerted by a bolt on the fibres of the pieces of timber that it holds together is of this nature. This point is considered at greater length when the subject of joints is discussed (para. **43**, Sec. IV). Bearing stress.

6. As in all other cases, the stresses due to the strength of the material must exactly counterbalance those due to the loads up to the instant of failure. In Section III the stresses due to the loads have been expressed in terms of the bending moment produced by them, and it follows that for equilibrium this moment must be equal to the moment produced by the stresses in the beam resisting failure. This moment is known as the moment of resistance, and denoted by M_r. Transverse stress.

When a beam is bent under a transverse load the stresses at all points of a cross-section are not uniform, but increase outwards, in compression and tension respectively, from zero at the neutral axis through the centre of gravity of the section, to maxima values at the fibres most remote from this neutral axis. It is most important that this extreme fibre stress should not exceed the safe stress decided on for the material under consideration. Extreme fibre stresses.

7. For strains within the elastic limit of the material the moment of resistance is given by the following expression :— Moment of resistance.

$$M_r = r \, . \, Z$$

The symbol r denotes the maximum intensity of stress, that is, the intensity of stress in the fibres most remote from the neutral axis. Its value should not exceed the safe intensity of stress, and consequently depends upon the material and the factor of safety. The symbol Z stands for the section modulus of the section in question, and is quite independent of the material of which the beam is composed. Its values, for the sections of beams commonly met with in practice, are given in Table E (p. 41) (Pl. X).

If the section is symmetrical about the neutral axis, the extreme fibres in tension and compression will be at the same distance from the neutral axis, and consequently the intensity of stress in them will be the same. The value to be given to r will then depend upon which is the smaller, the safe intensity of stress in tension or in compression. If the section is not symmetrical, the greatest intensity will occur in the fibres most remote from the neutral axis, and may therefore be either in tension or in compression. As a rule the value of r will be determined by the stress in these extreme fibres, but if a material has a distinctly different strength in tension and compression it may happen that the greatest intensity will have to be reduced Value of extreme fibre stress.

below what would be safe for that form of stress, to allow for the smaller value necessary for safety for the other kind of stress.

Section modulus.

8. The value of the section modulus itself is given by the following expression :—

$$Z = \frac{I}{y}$$

where I stands for the moment of inertia of the section in question, and y is the distance of the most remote fibre from the neutral axis.

Values for round and rectangular sections.

The values of the section modulus for round and rectangular sections should be specially noted, as these are the sections that occur in the majority of cases in practice. The value for round sections can be taken as approximately—

$$\frac{D^3}{10}$$

where D is the diameter of the beam. The value for rectangular beams is—

$$1/6\ bd^2$$

where b is the breadth, and d the depth of the beam.

Graphical determination of the section modulus.

A graphical method for determining the section modulus for sections not included in Table E is given on p. 86.

Calculation of members under transverse stress.

The calculation of members under a transverse load is therefore as follows :—

(1) Ascertain the loads that will come on that member.
(2) Consider which of them are "live," and convert them to their "equivalent dead load."
(3) From the position and arrangement of these loads, ascertain the position and value of the M_{ff}.
(4) This value must be equated to the value of the M_r at that cross-section.
(5) To do this, a value for the extreme fibre stress must be chosen, depending on the material to be used and the factor of safety, and the section so chosen, that this value, multiplied by the section modulus, will be equal to the value of the M_{ff}.

In this calculation the same units must be employed in the evaluation of M_{ff} and M_r.

Calculation of road-bearers.

When the transverse members to be calculated consist of road-bearers, evenly spaced across the transom, it is usual to assume that the outer one on either side only takes half the load taken by the remainder. Thus, in any calculation where the number of road-bearers is concerned, the number found to be necessary by the calculation must be increased by one. When the road-bearers are placed in definite groups, as, for example, below the wheel tracks of a heavy gun, this allowance is not necessary.

I. Find the size of a round larch spar to stand a concentrated load of 6 cwt. at the centre of a 7 foot 6-inch span— Examples.

$$M_{ff} = \frac{W\,L}{4} = \frac{6 \times 90}{4} \text{ inch-cwts.}$$
$$= 135 \text{ inch-cwts.}$$

Taking the ultimate strength of larch as 5,000 lbs. per square inch, and taking a factor of safety 4, r becomes 1,250 lbs. per square inch, or $\frac{1,250}{112}$ cwts. per square inch. If the mean diameter of the spar is D inches—

$$Z = \frac{D^3}{10} \text{ approximately}$$

therefore—

$$135 = \frac{1,250}{112} \times \frac{D^3}{10}$$

whence $D^3 = 121$ nearly, and the diameter of the spar should be 5 inches.

II. It is required to find what distributed live load five rectangular fir road-bearers, each 9 inches by 3 inches in section, can safely carry over a clear span of 20 feet. For this material the ultimate strength against compression is less than that against tension, and can be taken as 6,000 lbs. per square inch. With a factor of safety 5, r becomes 1,200. If each beam is supposed to be placed on edge, the breadth is 3 inches and the depth 9 inches. Then—

$$Mr = 1,200 \times \frac{3 \times 81}{6} \text{ inch-lbs.}$$
$$= 48,600 \text{ inch-lbs.}$$

Thus the total moment of resistance of the five road-bearers deducting one for the reason given above, is—

$$4 \times 48,600 \text{ inch-lbs.}$$
$$= 194,400 \text{ inch-lbs.}$$

Suppose the total distributed load on the bridge to be w lbs. per foot run. This includes the live load it has to carry the weight of the roadway, and the weight of the road-bearers themselves. Then—

$$M_{ff} = \frac{\frac{w}{12} \times (240)^2}{8} \text{ inch-lbs.}$$
$$= 600\, w \text{ inch-lbs.}$$

Then—

$$600\, w = 194,400$$

whence—

$$w = 324 \text{ lbs. per foot run.}$$

The weight of the roadway can be taken as about 70 lbs. per foot run, and that of the beams themselves together about 30 lbs. per foot run. This must be deducted from the above value of w, leaving 224 lbs. per foot run. This is the equivalent dead load; the live load is, therefore, assuming the usual allowance to be made—

$$= \frac{2}{3} \times 224.$$

$$= 149, \text{ or say } 150 \text{ lbs. per foot run.}$$

Rough formulæ.

9. Although it is desirable to use the foregoing methods in calculations for transverse members, the following rough formula may be used for hasty work:—Let W be the distributed weight in cwts. which is to pass over the beam. This is supposed to be a live load, but only the actual dead weight is to be taken, and no allowance need be made for the superstructure, provided it does not exceed about $\frac{1}{6}$ W. If the actual load is not distributed but concentrated at the centre, W must be taken as twice this weight, as the bending moment, due to the concentrated load at the centre of a supported beam, is twice that due to the same total load distributed. For a cantilever with a distributed load, W must be taken as four times the load; and if the load is concentrated at the end, W must be taken as eight times the load.

Let b be the breadth of the beam in inches.
d be depth of the beam, or the diameter of a round spar, in inches.
L be the span in feet.
k be a coefficient depending on the material.

Then for round spars—

$$W = \frac{6}{10} \frac{d^3}{L} \times k$$

and for rectangular beams—

$$W = \frac{bd^2}{L} \times k$$

For—

Larch and cedar	$k = 1$
Baltic fir	$k = 5/4$
American yellow pine	$k = 6/4$
Other firs and pines, and for beech, birch and English oak	$k = 7/4$

The value of k for any other wood can be got by dividing its ultimate stress in lbs. per square inch by 5,000.

These formulæ give a factor of safety of about 3. If it is desired to use any other factor of safety a corresponding alteration must be made in the formula, by dividing the value taken for W by 3, and multiplying it by the new factor of safety.

While the above rough formulæ are based on the same general principles as before, they owe their simple form to the units in

which the variables are expressed and the conditions assumed. Any alteration in these units or conditions will make these formulæ inapplicable.

A bridge has to be made to take the 4·7-inch gun over a gap of 10 feet. Seven road-bearers are to be used. Find their dimensions. The weight on the gun wheels can be taken as 85 cwts., and as the axle distance is more than 10 feet, it is clear that the greatest bending moment will occur when the gun wheels are at the centre of the span. The load is concentrated, and must therefore be multiplied by 2, making W = 170. There are seven road-bearers, and with the usual assumption about the two outer ones this value must be divided by 6 to give the value of W for any of the inside road-bearers. Example.

I. Assume that they are to be round fir spars. Then—

$$\frac{170}{6} = \frac{6}{10} \times \frac{d^3}{10} \times \frac{5}{4}$$

whence d is 8 inches approximately.

II. Assume that they are to be rectangular oak beams. Then—

$$\frac{170}{6} = \frac{bd^2}{10} \times \frac{7}{4}$$

whence $bd^2 = 162$ nearly. Here both b and d are unknown. It is, however, generally convenient to take d equal to about $2\,b$, and hence beams $3\frac{1}{2}$ inches by 7 inches would be suitable.

Experimental values.

The value of the ultimate strength against tension and compression of the more common materials is given on p. 80; but it may sometimes happen in field structures that the material to be used is a timber the values of whose ultimate tensile and compressive stresses are unknown. In such a case it is necessary to carry out experiments to discover these values. It would be a practically impossible task to find out, with field appliances, the strength of such material under direct tensions or compressions. The experiment carried out is therefore as follows :—A large baulk is taken, supported in a suitable manner, and loaded centrally until it breaks. Let the weight at which it breaks be W lbs. Then if the unsupported span is L inches, the M_{ff} at the time of failure was at the centre, and was—

$$\frac{WL}{4} \text{ inch-lbs.}$$

Assuming that the section modulus of the beam was Z′, and that the elastic law held true up to the time of fracture, the moment of resistance at that time was—

$$r' \,.\, Z'$$

Equating M_{ff} and M_r —

$$r' = \frac{WL}{4Z'}$$

This equation gives the value of r', the ultimate maximum intensity of stress, in terms of the known weight and dimensions. The accuracy of this determination depends on the assumption

that the elastic law held up to the time of failure; but this is by no means the case. As the intensity of stress in the extreme fibres increased, the elastic limit was passed, with the result that the strain in these fibres was more than proportional to the stress, thus throwing more than the theoretical intensity of stress on the fibres nearer the neutral axis. The value of r' is therefore too high, and in fact this value is not taken as the ultimate intensity of stress, but is called the modulus of rupture. Its excessive value must be allowed for by using a larger factor of safety. The baulks experimented upon should be as large as possible in order to avoid the unnaturally superior quality of small selected specimens of the material. The baulks should also be rectangular in section, and not round, as this latter section largely increases the error due to the failure of the elastic law. In the case of a great many timbers, the only available information as to their strength is their modulus of rupture.

Stiffness.

10. The deflection of a beam under a load is not an indication of its strength, and practically a beam that is strong enough as regards transverse stress is almost always stiff enough for ordinary field purposes. If there is any doubt, it must be strutted or stiffened. A beam whose depth is considerable in proportion to its width is stiffer, for the same strength, than a beam more nearly square in section, but in using beams of such dimensions the possibility of failure by longitudinal shearing must not be forgotten.

Beams of insufficient scantling.

11. When the timber or other material is of insufficient scantling to carry the loads that will be brought on the various members, two or more beams may be placed on one another, but the total strength must not be calculated as if they formed one beam. The strength of each beam must be calculated separately, and the total strength will be obtained by adding the results together.

Tapering spars.

In the majority of cases of transversely loaded beams in field structures, the M_{ff} is to be found at the centre of the span. Thus, in using round spars, even with a considerable taper, the central section should be taken for purposes of calculation, and not the smallest one.

Compound loading.

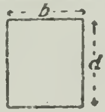
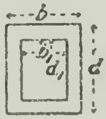
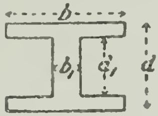
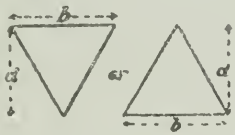
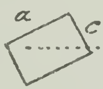
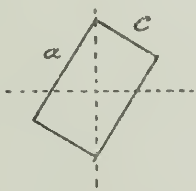
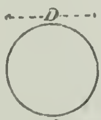
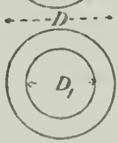
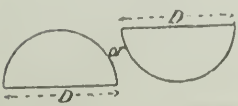
When a beam is loaded in a compound way, for example, under a transverse load as well as a thrust, the stress at any point will be the algebraic sum of the stresses due to the loading separately. The maximum value of this must be used in any calculations that are necessary.

Shearing stress.

12. Shearing stress does not enter very largely into the calculations for field structures. The solid beams usually employed, if capable of withstanding the transverse stress brought upon them, will as a rule be more than sufficient to resist the shear. It may be mentioned that to avoid the chance of a beam failing by longitudinal shear, its depth (in the case of a fir beam) should not be more than 1/10 of the span for a distributed load, nor more than 1/5 for a central load. The question of shear has to be more taken into consideration in the design of joints.

TABLE E.

Values of Section Modulus, &c.

Form of Section.		Section Modulus. $Z=\frac{I}{y}$	Moment of Inertia. I	Extreme Fibre Distance. y
Solid rectangle.		$\frac{b\,d^2}{6}$	$\frac{b\,d^3}{12}$	$\frac{d}{2}$
Hollow rectangle.		$\frac{b\,d^3-b_1d_1^3}{6\,d}$	$\frac{b\,d^3-b_1d_1^3}{12}$	$\frac{d}{2}$
H section.		$\frac{b\,d^3-(b-b_1)\,d_1^3}{6\,d}$	$\frac{b\,d^3-(b-b_1)d_1^3}{12}$	$\frac{d}{2}$
Triangle.		$\frac{b\,d^2}{24}$	$\frac{b\,d^3}{36}$	$\frac{2\,d}{3}$
Rectangle with a diagonal horizontal.		$\frac{a^2\,c^2}{6\,\sqrt{a^2+c^2}}$	$\frac{a^3\,c^3}{6\,(a^2+c^2)}$	$\frac{a\,c}{\sqrt{a^2+c^2}}$
Rectangle with a diagonal vertical.		$\frac{a^5c+a\,c^5}{6\,(a^2+c^2)^{\frac{3}{2}}}$	$\frac{a^5c+a\,c^5}{12\,(a^2+c^2)}$	$\frac{\sqrt{a^2+c^2}}{2}$
Solid circular section.		·0982 D^3	·0491 D^4	$\frac{D}{2}$
Hollow circular section.		·0982 $\frac{D^4-D_1^4}{D}$	·0491 $(D^4-D_1^4)$	$\frac{D}{2}$
Semi-circular section.		·0238 D^3	·00686 D^4	·288 D

Timber.

Timber.

13. As a rule in hasty field engineering it is only possible to make use of such timber as may be available close to the site of the work. Such timber will either be—

(*a*) Felled and trimmed on the spot, and, if necessary, converted into rectangular scantlings.
(*b*) Collected from timber stores in adjacent towns and villages, or from railway depôts.
(*c*) Obtained by demolishing structures containing timber, such as sheds, floors, doors and roofs.

Useful varieties.

The undermentioned are the best of the ordinary descriptions of timber to use for the purposes named :—

Piles	Oak, beech and elm.
Posts	Chestnut, acacia and larch.
Great strength	Teak, oak, greenheart, pitch pine, Kauri pine and Oregon pine.
Durable in wet positions...	Oak, beech, elm, teak, alder, plane, acacia and greenheart.
Large timbers	Baltic fir, oak, chestnut, mahogany, pitch pine and teak.
Bridging planks	Baltic and other firs, spruce.

Strength.

14. Of all structural material timber is the most variable in strength and other qualities, two pieces of the same tree or even from the same log often producing very different results. The chief reason for this is that timber being a built-up structure is subject to internal strains, and these strains vary with each piece of timber. It is consequently necessary to allow a large factor of safety in timber structures, unless the timber has been specially selected as the best quality of its kind obtainable. For important work it is always advisable to test samples, and not to trust entirely to the results of any previous experiments.

The results given in Table F (p. 78) have been compiled from various authorities. To obtain the value of the modulus of rupture from experiment, the procedure described above may be followed. Care must be taken, by protecting them with iron plates, that the fibres next the supports and the weight are not crushed.

As a general rule the weight and density of seasoned timber give a measure of its strength, the heaviest timbers, even those of the same species, being the strongest in compression and bending tests ; but density is no criterion of tensile strength, and some comparatively light timbers have great tensile strength, as, for instance, ash and hickory.

The strength of a piece of timber is much greater for tension and compression along the grain than across it, in which direction the fibres have not to be broken, but merely

torn from one another, the resistance being more a question of adhesion than strength in the usual sense. Further, the strength of a piece of wood depends upon the part of the tree from which it is cut, whether from the heartwood or sapwood and whether from the upper or lower part of the tree. Its strength is also affected by the amount and kind of seasoning it has undergone, the place and soil in which it was grown, the age of the tree and the season at which it was cut down.

Superimposed beams.

When baulks of timber have to be superimposed upon one another to obtain the necessary strength, no appreciable increase of strength is obtained by bolting the baulks together. It has been found by experiment that the bolts bent at each joint of the baulks, and were pressed sideways into the timber to an extent which showed that the baulks slid upon one another. A slight increase in strength can be obtained by securing them with hard wood keys, wedges, or bolts; the latter should be inclined.

Timber columns.

Timber columns are fairly uniform in tests up to about 15 diameters long, and up to this point give way by direct crushing. In longer columns the larger number fail by lateral flexure or buckling sideways, and generally fail at knots.

Classification.

Trees are divided according to the manner in which new material is added to the section. This is either on the outside of older growth and next to the bark, or else it is inside, distributed over the section. The timber produced is correspondingly dissimilar, and the two general divisions into which the trees are thus separated are known as exogens and endogens. Exogenous trees are further divided into broad-leaved trees and needle-leaved conifers.

It is usual to associate the terms broad-leaf, deciduous and hard wood, and likewise the terms needle-leaf, conifer, evergreen and soft wood. While generally correct, this is not always so. For most practical purposes the timber used in engineering works may be divided into two classes :—

Soft wood.—Including firs, pines, spruce, larch and all cone-bearing trees.

Hard wood.—Including oak, beech, ash, elm, mahogany and so forth.

In tropical countries, however, endogenous trees such as palms, bamboos and canes are most useful, and although from the nature of their structure it is not possible to cut them into rectangular scantlings, yet they may often be used as logs. As the layers increase in density from the centre to the circumference the timber is well adapted for use in columns and piles. It is deficient in rigidity, however, although light and strong. The stems of palm trees are solid, but those of some of the grasses, such as bamboo, are hollow. Weight for weight, the wood of the bamboo is about twice as strong as the strongest exogenous timber in cross-bending.

Rattan is characterized by toughness, length, lightness and pliability, and can be usefully employed as a substitute for cordage.

Botanical names. Woods appear to be more numerous than is actually the case, because several names are often applied to a single product. Such confusion can only be avoided by regarding the recognized botanical nomenclature. Even so, however, a great number of species exist, but the great majority of wood used in construction comes from but few of them.

Conversion of timber. **15.** Trees are most valuable for felling just before they reach maturity, after which each succeeding year produces a certain amount of deterioration in the wood. The passing of this period is shown by the topmost branches and branchlets becoming stunted and thick, the tree then being called "stag-headed." When selecting a tree for felling one with an abundance of young shoots, and whose topmost branches look strong, pointed and vigorous, should be chosen. This is the most certain evidence that it has not yet passed maturity.

Wood is composed of sapwood and heartwood, the former being the external and youngest portion of the tree. The sapwood is much the weakest, and being on the outer circumference, always forms a large proportion of the timber, up to 40 per cent. or more. Young trees are almost all sapwood, and are practically useless as timber.

Bamboos obtain their full growth in about a year, but must then stand for three or four years in order to season or harden.

Details as to felling trees and converting them into rectangular scantlings are given in "Military Engineering," Part I, paras. 71 to 78.

In reducing timber from the log or baulk to scantlings, the dimensions and form that the timber ought to possess when actually in use should be borne in mind, in order that proper allowance may be made for the alteration that will take place in consequence of the action of the atmosphere, which has some effect even upon well-seasoned timber.

Experiments have shown that timber beams having the annual rings parallel to their depth are stronger than those which have the rings parallel to their width.

The strongest rectangular beam that can be cut from a round log has its depth to its breadth in about the proportion of 10 to 7. The stiffest rectangular beam that can be cut from a round log has its depth to its breadth in about the proportion of 7 to 4.

Green timber. Trees, when freshly felled, are not properly fit for use until they have been somewhat seasoned. This is frequently impossible in field engineering, and allowance must then be made for the lack of strength in green timber. Fresh cut timber has only about half the maximum strength to which it will attain when all but about 4 or 5 per cent. of its own weight of water has been dried out of it. For comparison of different woods

it is necessary to adopt a definite standard percentage of moisture—from 12 to 15 per cent. is usually chosen, this being the amount retained after good air drying. With a moisture percentage below 10, water is rapidly absorbed from the atmosphere. The weakening effect of moisture which has been re-absorbed by timber previously dried is almost identical with that of the moisture originally in the timber. On the other hand, a baulk of green timber, although it will not bear nearly so much load as a dry one, will not fail so suddenly.

16. Heart-shakes are radial splits from the centre of the log. Several shakes radiating from the centre constitute a star-shake. **Defects in timber.**

Seasoning checks are radial splits, which extend from the circumference towards the centre. They occur in the log when drying.

Ring-shakes or cup-shakes are openings between the annual rings, which sometimes extend right round the log, in other cases only partially so.

Knots are objectionable features in timber, but cannot be avoided. Very large knots, especially at the edges of timber which has to stand a heavy stress, are a cause of considerable risk, and the more so if they are on the side in tension.

Timber is liable to decay, and many names refer to practically the same cause of disintegration, such as wet rot, dry rot and disease. In old trees the inner portions of the heartwood are apt to decay, and in timber removed from other structures rot of some kind is likely to have occurred, especially in the ends of timbers built into brickwork, &c. **Decay in timber.**

Good timber should be visibly free from disease. A log apparently sound, as far as external appearances go, may be full of dry rot inside, which can best be detected by boring into it with a gimlet or auger and noting the smell and appearance of the dust extracted from it. If a piece of sound timber is lightly struck or scratched at one end, the sound can be distinctly heard by a person placing his ear against the other end, even if the baulk is 50 feet long; but if the timber is decayed, the sound will be very faint, or altogether prevented from passing along the baulk.

Timber when freshly cut should smell sweet. The surface should not be woolly nor clog the teeth of a saw, but should be firm and bright, with a silky lustre when planed. A disagreeable smell betokens decay, and a dull chalky appearance is the sign of bad timber. The colour of good timber should be uniform throughout. When it is blotchy or varies much in colour from the heart outwards, or becomes pale suddenly towards the limit of the sapwood, it is probably diseased.

Timber, both in its growing and converted states, is subject to the attacks of worms and insects. When these exist in large numbers they remove so much of the wood as seriously to impair

the strength of any structure dependent upon the timber, and in some cases they destroy the baulks altogether. This is especially the case with timber used in submarine work, particularly in tropical climates.

Preservation of timber.

Painting and tarring preserve timber if the wood is thoroughly seasoned before they are applied, otherwise the filling up of the outer pores only confines the moisture and causes rot.

Creosoting is about the most successful of all preservative processes at present known. To a certain extent it renders timber proof against sea worms and white ants.

Market sizes.

17. In countries where timber is very scarce, too hard or too heavy, or otherwise unsuitable, and when time permits of obtaining a supply of timber from a distance, a knowledge of the natures and limiting sizes of timber in ordinary commercial use will assist in preparing demands for material suitable for general field purposes in war. For information on this subject reference can be made to Table G (p. 79).

Weight of timber.

18. The weight of timber is very uncertain, and the great variation in the weights given by different authorities is mainly due to the greater or lesser amount of moisture in the timber; the weight also of each piece of a log or tree differs from adjoining pieces.

The weight per cubic foot should be taken as that for well-seasoned timber, say, with 12 to 15 per cent. of moisture.

Ordinary pine timber, when freshly cut, contains about from 40 to 60 per cent. of moisture by weight. That is to say, the weight of the same wood, when dried to 15 per cent. water, will be from two-thirds to one-half of its weight when green.

The weight of timber is increased from 7 to 12 lbs. per cubic foot over the weight of well-seasoned wood by the process of creosoting.

Weight and centre of gravity of round spars.

The weight per cubic foot and the position of the centre of gravity of round spars can be found from Pls. XV and XVI.

Iron and Steel.

Iron and steel.

19. Iron and steel may be available in the field in the following forms :—

(1) Rods and bars of various sections, rectangular and round.—These would be useful as tension members in certain bridges. The safe working stress on certain sections is given in Pl. XVII.
(2) Plates.
(3) Rolled joists, either from a builder's yard or taken from the top of a shop front.—These would be useful as road-bearers for bridges for heavy traffic.
(4) Built-up girders could sometimes be obtained for large bridges.

(5) Rails from a railway or tramway depôt.—These would be useful as road-bearers. Standard types with their properties are given in Pl. XVIII, and the safe load on these standard patterns is given in Pl. XIX.
(6) Sheets, plain or galvanized, smooth or corrugated.—These might be employed as a roadway for bridges, with suitable precautions as to covering them with earth in the case of animal traffic.
(7) Wire rope and wire from which ropes can be made.—These are dealt with in detail in para. **29.** The safe stress in various standard gauges of wire is given in Pl. XVII.
(8) Chains.—These are dealt with in para. **37.**
(9) Nails, spikes, bolts and dogs.—These are dealt with in paras. **46, 47** and **51.**

Average values of the ultimate stress and the safe working stress for various natures of iron and steel are given in Table H (p. 80).

Cordage, Wire Rope and Chain.

20. Officially, hemp and fibre ropes are termed "cordage," while the word "rope" is used to denote iron or steel wire rope. Practically rope is used to denote both classes. Cordage and rope.

The size of a rope is denoted by its circumference in inches. Its length is measured in fathoms. It is issued in coils of a definite number of fathoms—cordage in coils of 113 fathoms, bolt and three-strand manila 122 fathoms, and steel wire rope 100 fathoms.

Cordage, for military purposes, is made from the fibres of hemp, manila and coir, and is supplied by special contractors under stringent specifications as to quality. But in the field local supplies would often have to be used, and in such cases it would not be safe to reckon on the same high standard. Cordage.

Hemp fibre is obtained from the hemp plant, and is found in three main varieties, the strength of which differs considerably. Hemp.

Italian hemp has a white silky fibre, and is the strongest of the three varieties. It is used in the manufacture of all white hemp cordage, except spunyarn, and for tarred bolt rope cordage. Riga hemp has a green tinge and is coarse grained. It is always tarred, and is used for tarred hawser-laid ropes up to 6 inches, and for lashings. Inferior qualities are made into spunyarn. Petersburg hemp is also greenish and coarse grained, and is the weakest of the three varieties. It is always tarred and is used for tarred hawser-laid ropes over 6 inches. It is also made into spunyarn.

Manila fibre is obtained from the outer fibres of the leaf-stalk of a species of plantain. It is more elastic than hemp fibre, and rope made from it is less affected by wet and less likely to kink; it is, however, rather too elastic for lashings. Manila.

Coir fibre is obtained from the outer husk of the cocoanut. Coir.

It is always used in an untarred condition. It is very light and elastic, and will float until it becomes saturated with water. When constantly wet it does not rot as hemp would.

Cotton. In manufacturing towns cotton rope might be obtained from the driving ropes of machinery.

Manufacture. Several fibres of the material are twisted together to form a yarn. Several of these yarns twisted together form a strand, and three or more strands twisted together form a rope.

The system on which the strands forming the rope are twisted together is called the "lay"; the variations in system are as follows:—

Bolt-rope.
Hawser-laid, 3-strand.
Hawser-laid, 4-strand or shroud-laid, with a central core in addition to the four strands.

These terms really indicate the tightness with which the strands are laid up, and the three varieties can be measured in the finished rope by the angle between the direction of each strand and the direction of the centre line of the rope. These angles are as follows:—Bolt-rope, 36½ degrees; hawser-laid, 3-strand, 42 degrees; and hawser-laid, 4-strand, 45½ degrees.

In addition to the foregoing, three 3-strand ropes are sometimes laid up together, the rope thus formed being termed cable-laid.

Increasing the angle of the lay makes the rope weaker, but more durable against wear.

Tarring rope weakens it, but preserves it from rotting. If white cordage receives proper care and stowage it should not deteriorate, and it is some 30 to 50 per cent. stronger than tarred, and about 20 per cent. lighter.

Spunyarn. Spunyarn is made from three to nine yarns. It is issued in coils of 56 lbs. weight, and 1 lb. is about 5 fathoms.

Identification of cordage. To identify a piece of cordage the following points must be specified:—Material, lay, whether tarred or white, and size.

Service varieties. The varieties of service cordage, as given in the Vocabulary of Stores, are given in Table J (p. 81).

Weight of cordage. **21.** The weight of various patterns of cordage differs very considerably, but as a rough rule the weights may be taken as follows:—

Hemp and manila, tarred	$\frac{C^2}{4}$	lbs. per fathom.
Hemp and manila, white	$\frac{C^2}{5}$	" "
Coir	$\frac{C^2}{10}$	" "

where C is the circumference in inches.

Strength of cordage. **22.** The strength of cordage is an important point, but its tensile strength alone need be considered. The strength of

cordage of the same nature varies within a large range, but the average for any particular kind depends upon—

(1) *Material.*—The following are in decreasing order of strength:—Italian hemp, manila, Riga hemp, Petersburg hemp and coir.
(2) *Lay.*—The following is the decreasing order of strength:—Bolt rope, hawser 3-strand, hawser 4-strand.
(3) Whether tarred or white. The former is considered about 30 per cent. weaker than the latter.
(4) *Size.*—The larger sizes of rope are not so strong in proportion as the smaller ones.

In common with other materials the strength of cordage ought to be expressed by the intensity of the ultimate stress. As the sizes of cordage, however, are given in terms of the circumference, it is found more convenient to express the strength in terms of a load, multiplied by the square of the circumference.

Government specifications lay down the minimum breaking loads for all varieties of cordage supplied officially, and from these values the figures in Table J have been derived. Cordage obtained locally probably would not be of so good a quality originally, and would also generally have deteriorated considerably with age. Table K (p 81) gives similar figures for certain ropes obtained commercially and tested to destruction. Maximum and minimum values are given, as well as average ones, to show the range of ultimate stress values, even in new ropes.

23. More than one-third of the ultimate load should never be put on a rope, and a larger factor of safety should generally be employed, especially if using worn ropes and with a live load. For important work a piece of the cordage to be employed might be tested to destruction, and the amount of the working load thus determined. For hasty work in the field a rough rule is necessary which must give enough margin to be safe with the weakest variety of cordage likely to be used. The safe working load of all cordage in the field, with the exception of coir, has consequently been laid down as follows:— Working loads.

$$C^2 \text{ cwts.}$$

where C is the circumference in inches. This may be increased, for good cordage, in good condition, up to a maximum of—

$$2\ C^2 \text{ cwts.}$$

The safe working load on coir cordage can be taken as—

$$\tfrac{1}{4}\ C^2 \text{ cwts.}$$

It may be noted that the expression C^2 cwts. gives an intensity of stress of about 1,400 lbs. per square inch.

24. Cordage stretches considerably when loaded. In certain cases it might be useful to know approximately the amount of stretching that will take place under a given load. Stretching.

When a piece of cordage has been in use some little time a fair proportion of the stretching becomes permanent, and the elongation for any given load will therefore be less. Different pieces of cordage, even of the same nature, vary in the amount they stretch, but the following rough rules will give the average values for new cordage; due allowance would have to be made for cordage that has been in use :—

$$\left.\begin{array}{ll}\text{All hemp and manila cordage,} & \frac{1}{2}\,\frac{\sqrt{S}}{C} \\ \text{Coir and cotton cordage...} \quad \text{...} & \frac{\sqrt{S}}{C}\end{array}\right\}\ \text{Percentage of elongation on original length.}$$

where S is the total stress in lbs. and C the circumference of the rope in inches.

Practical points.

25. The strength of ropes when slung over hooks or fastened by knots is decreased about 30 per cent. This is due to the fact that at the bend the intensity of stress in the fibres is not uniform, and some of the outer fibres are, in consequence, liable to fail. If it is required to work the rope up to its full working load, thimbles or their equivalent must be used, and the mode of attachment so chosen that no sudden bend takes place in the rope. If thimbles are not available, waste or old sacking can be inserted between the hook and the bight into which it is hooked.

In uncoiling a new coil of cordage, pass the end which is at the core through the coil to the opposite side, and draw it out; the turns will then run out without kinking.

Cordage should always be coiled down in the same direction as that in which it is laid up. Service cordage is made up right-handed, and should consequently be coiled down with the sun—that is, in the same way as the hands of a watch. This will prevent it from kinking.

Cordage should be kept as dry as possible, and when not in actual use should be coiled clear of the ground. If unavoidably exposed to weather it should be protected by tarpaulins or other coverings. It should never be returned to store nor, if it can be avoided, coiled down in a wet condition. Cordage stowed away damp or in damp stores, or once wet with salt water, rapidly deteriorates and becomes untrustworthy. This fact accounts for the small stresses at which seemingly good cordage will part, and points to the necessity of exercising great care before taking rope into use in heavy operations. A rope may appear to be good, but it may be worm-eaten or mouldy at the heart. When this is the case the interior of white rope may have a slaty-grey appearance.

Use of cordage.

26. The following technical terms employed with cordage are in common use and their meaning should be understood :—

(1) **The running end** is the name given to the free end of a rope.

(2) **The standing part** is the rest of the rope.

(3) **Belaying a rope** is making it fast to another object, and a rope made fast is said to be *bent*.

(4) **Paying out** or *easing a rope* is slackening it out.

(5) **A bight** is a loop formed on the rope so that the two parts lie alongside one another.

(6) **A half-hitch** is a loop made so that one part crosses the other.

(7) **Whipping a rope** is tying a piece of twine round the end to prevent it from untwisting and fraying. To whip a rope lay the end of the whipping along the rope, with its point towards the end, and take some turns round it and the rope towards the point. When half the required number of turns have been made, lay the end back from the point of the rope and lay the other end of the twine alongside the first, then twist the standing part of the loop so formed round its running part and the rope, until the required number of turns have been taken, after which pull the two ends, one towards the end of the rope and the other in the opposite direction, till they are tight, and cut them off close to the whipping. (Pl. XX, Fig. 1.)

Another way is to take a piece of twine about 2 or 3 feet long, according to the size of the rope, and place it with one end (*a*) lying to the right, the other (*b*) along the rope to the left. Wind the part (*c*) (*d*) (*f*) tightly round the end of the rope and the two ends of the whipping twine (*a*) and (*b*) the requisite number of times. Then by pulling the ends of the twine (*a*) and (*b*) the whipping is tautened up and completed. (Pl. XX, Fig. 2.)

(8) **Pointing a rope** is tapering the end so that it can more easily enter a hole or block.

(9) **Parcelling a rope** is putting canvas round it well daubed with tar, and binding it with spunyarn. This is used on portions of rope exposed to chafe.

(10) **Frapping** is the drawing together of the several returns of a rope or twine lashing by passing the rope or twine round all the returns.

(11) **Seizing a rope** is connecting two parts together with a lashing of spunyarn, &c. To seize a rope, take a piece of spunyarn and double it. Place the bight round both ropes to be seized and pass the ends of the yarn through the bight. Haul taut by pulling on the ends in opposite directions, and make fast with a reef knot after as many turns have been taken as are necessary. (Pl. XX, Fig. 3.)

Another way is to take the centre of the yarn and tie a clove hitch with it at the required point on one of the ropes; then take each part round and round the two ropes in opposite directions, leaving one end long enough to take two frapping turns between the ropes; the ends are then connected by a reef knot. (Pl. XXI, Fig. 4.)

All bends and many other knots can often be made more secure by seizing the running end to the standing part.

(12) **Mousing a hook** is securing a lashing of spunyarn to the mouth of the hook to prevent its clearing or disengaging itself from anything it may be hooked to. To mouse a hook, take a piece of spunyarn, double it, pass the bight round the back of the hook and the ends through the bight. Two or three turns are then taken with the ends in opposite directions round the back and point of the hook, frapped together and secured by a reef knot. (Pl. XX, Fig. 4.)

Another way is to make the centre of a piece of spunyarn fast with a clove hitch to the back of the hook. Both ends are passed round the back and point of the hook several times frapped and finished with a reef knot. (Pl. XXIII, Fig. 7.)

(13) A **gasket** is a flat-plaited part of a rope, used for stoppering. (See stopper hitch.) It is made from one or two pieces of rope, according to the size required. Seize the rope where it is intended to end the gasket, unstrand it up to the seizing, separate the yarns, slightly untwist them and whip their ends; then divide them into from three to nine portions, called foxes, and plait the foxes together. If the gasket is to be thinned off towards the end, the foxes must be thinned at intervals near the end of the plait. (Pl. XX, Fig. 5.)

Another way of forming a gasket is to unstrand a rope and lay the three strands side by side and serve them over with yarn.

A gasket can be made with an eye to it as follows:—Take a piece of rope, double the length required, form a bight in the centre of the rope and seize it at the end of the bight. Unstrand the rope up to the seizing and call the strands 1, 2, 3, and 4, 5, 6, respectively. Interweave these strands as follows—Pass 1 over 4 and under 5, and unite it to 6; 2 and 5 work together, and 3 works with 4, which crosses under 1. The whole of the yarns having been opened out up to the seizing and united in the order above, the three strands thus made are plaited together. To taper it off a few yarns are gradually taken off each strand. (Pl. XX, Figs. 6 and 7.)

The strength of a gasket when used as a stopper is found to be about 40 per cent. less than that of the rope it was made from.

(14) A **selvagee** is formed of rope yarns coiled into a circular form and **marled** down. To make it; plant two pickets at a distance apart equal to the intended length of the selvagee, wind yarn rope round them until the skein is thick enough, and then marl it all round with the same yarn, half-hitched round it at intervals of an inch, and finish off with two half-hitches. The pickets must not draw in at the top or else the yarns will not all be of the same length. (Pl. XX, Fig. 8.)

It can be applied to a rope or a spar, as shown in Pl. XX, Figs. 9 and 10; but the best way is to lay the middle of the selvagee on the cable, turn the right hand end round under the cable and take hold of it in the left hand; then pass the other end under the cable to the right, but riding over the first part, and take

it with the right hand. Pass the end, now in the right hand, to the left over the cable and the other end to the right overriding it, and so on till near the end of the selvagee, when the hook of the block is hooked into both loops. A selvagee holds well on wire ropes. It provides a quick way of applying a block to a spar, and is more quickly applied than a gasket for stoppering.

Knots and Splicing.

27. It is important that knots should be tied quickly, correctly and without hesitation. A knowledge of knots cannot be acquired from books; it is essential that practice in tying them should be continued until they are thoroughly learnt. Knotting.

Knots may be divided into several groups, as follows:—

I. Knots to make a stop on a rope.

Thumb knot.—To make this knot, pass the end of the rope over the standing part and then up through the loop thus formed. (Pl. XX, Fig. 11.) This knot is also used to prevent a knot from unstranding. Thumb knot.

Figure of eight knot.—To make it, pass the end of the rope under, round above and down below the standing part, then upwards through the bight thus formed. (Pl. XX, Fig. 12.) This knot is more secure than a thumb knot. Figure of eight knot.

II. Knots for joining or bending ropes together.

Reef knot.—This knot is made as follows:—Holding one rope in each hand, ends to the front, lay the end of the right-hand rope over the left, and take it towards the left once completely round that held in the left hand, so as to bring the point again to the front. Turn it back in the direction of and alongside its standing part over the original left hand end. Bring the latter up round the first end, down through the loop and haul taut. (Pl. XX, Fig. 13.) The standing and running parts of each rope must pass through the loop of the other part in the same direction—that is, from above downwards or *vice versâ*. If they pass in the opposite direction the knot is what is termed a *granny*, and when tightened up cannot be undone as easily as a reef knot can. (Pl. XX, Fig. 14.) A reef knot can be upset and the ends pulled out by taking one end of the rope and its standing part and pulling them in opposite directions. A reef knot is used for small dry ropes of the same size, with dry rope it is as strong as the rope; with wet rope it slips before the rope breaks, while a double sheet bend is found to hold. Reef knot.

Draw knot.—This knot is the same as a reef knot, except that a bight instead of an end is drawn through at A. (Pl. XXI, Fig. 1.) It can be cast off from a distance by pulling on the end B. Draw knot.

Single sheet bend.—This knot is made as follows:—Take a bight or double at the end of one rope, holding it in the left hand, and pass the end of the other rope held in the right hand up through this bight, down on one side, under and up over the bight, and under its own standing part. (Pl. XXI, Fig. 2.) Single sheet bend.

This is used for ropes of unequal size, or where the stress on the rope is not continuous. It is a more secure knot than the reef knot, but is more difficult to undo.

Double sheet bend.

In the **double sheet bend** the running end is passed twice round the bight and under its own standing part each time, without overriding. (Pl. XXI, Fig. 3.) It is used where greater security is required, especially with wet ropes, as it is found to hold till the rope breaks.

Hawser bend.

Hawser bend.—This bend is made as follows :—Make a bight at the end of one of the hawsers, take a half-hitch with the running end round the standing part, lash them together just beyond the hitch, and seize the running end to the standing part. Pass the end of the other hawser through the loop so formed, take a half-hitch round its own standing part, and seize as before. (Pl. XXI, Fig. 4.) This bend is used for very large cables. For greater security two half-hitches can be made in each hawser. By taking a complete turn with one rope round the loop of the other before making the half-hitches, the strength of the bend is largely increased, more bearing surface being obtained, and the tendency to part at the loop to a great extent done away with.

III. Knots to attach ropes to other ropes or spars.

Half-hitch.

Half-hitch.—This is made by passing the running end of a rope round the standing part and bringing it up through the bight; it may be seized to the standing part. (Pl. XXI, Fig. 5.)

Two half-hitches.

Two half-hitches are made as follows :—With the end of the rope in the right hand and the standing part in the left, pass the end of the rope round the standing part, and up through the bight, thus forming one half-hitch. Two of these alongside one another complete the knot. (Pl. XXI, Fig. 6.) The end may be lashed down or seized to the standing part by a piece of spunyarn, which adds to its security, and prevents the end from slipping. This is especially used for belaying or making fast the running end of a rope on to its own standing part.

A round turn and two half-hitches.

Round turn.—This and two half-hitches is the same as the last, with the exception that a complete turn is taken round the spar or other object to which the rope is to be fastened, and the half-hitch is taken afterwards round the standing part. (Pl. XXI, Fig. 7.) Should the running end be inconveniently long, a bight of it should be used to form the half-hitches.

Rolling hitch.

Rolling hitch.—This is made as follows :—With the end of a rope take two turns over the spar, then make two half-hitches round the standing part, the end being seized if the rope is stiff. (Pl. XXI, Fig. 8.) This hitch is always easy to cast off.

Fisherman's bend.

Fisherman's bend.—This bend is made as follows :—A complete turn is taken round the ring or other object to which the rope is to be fastened, and the end is passed over the standing part between the turn and the ring, over its own part, thus forming one half-hitch, and a second half-hitch is taken round the

standing part alone. (Pl. XXI, Fig. 9.) This is used in pontooning to fasten cables to the rings of anchors, and in all water work where a give-and-take motion has to be met.

Clove hitch.—This hitch can be made in two ways, dependent on whether it is possible to slip the knot over the end of the spar or not. In the first case, grasp the rope with the left hand, back down, and right hand, back up. Reverse each hand so as to form two loops. (Pl. XXI, Fig. 10.) Lay the two loops together so that the one held in the right hand is inside the other, and slip the double loop so formed over the end of the spar. (Pl. XXI, Fig. 11.) When the rope has to be secured to a spar over the end of which the knot cannot be slipped, pass the end over and round the spar and bring it up to the right of the standing part and again over and round the spar, to the left of the first turn, and bring the end up between the spar, the last turn, and the standing part. (Pl. XXI, Fig. 12.) This is especially used for securing the running end of a rope to a spar, as, for instance, in beginning a lashing; it is also used for securing guys to the heads of spars. When used in lashing spars the end should be twisted round the standing part; and, for guys, seized to the standing part. A rope end secured by a clove hitch breaks near the clove hitch with less weight than if eye-spliced, or bent and seized. As this knot is one of the most useful and most frequently required, considerable practice should be devoted to making it in various positions. It will be noticed that a clove hitch is the same as two half-hitches pulled together. Clove hitch.

Split clove hitch.—This is the same as a clove hitch, except that the two component half-hitches are separated by some portion of the object to which the rope is secured. It is used, for instance, in making fast a buoy line to the crown of an anchor. (Pl. XXI, Fig. 13.) Split clove hitch.

Magnus hitch.—This hitch is made by passing the end of a rope twice round a spar, then bringing it up before the standing part, passing it again round the spar on the opposite side to the first turn, and up through the bight which is made, the end part being jammed by it. (Pl. XXI, Fig. 14.) This is used for making fast to round spars when much friction is necessary to prevent slipping. Magnus hitch.

Draw hitch.—To make this hitch pass a bight of the running end round the holdfast. Pass a bight of the standing part through the first bight, and haul taught on the running end. Pass a bight of the running end through the second bight and haul taut on the standing part. (Pl. XXII, Figs. 1, 2 and 3.) This knot will stand a give-and-take motion, and can be instantly released by a jerk on the running end. It is used to secure a head rope, boat's painter, &c., to a post, ring or rope, so that it can be instantly released. Draw hitch.

Timber hitch.

Timber hitch.—This is made as follows :—Pass the end of the rope over and round the spar and round its own standing part close to the spar. Then twist it at an easy angle two or three times back round itself, and haul the fall taut, thus jamming the twisted end against the spar. (Pl. XXII, Fig. 4.) It is used for securing foot-ropes, &c., and can be easily undone when the strain is taken off it.

Killick hitch.

Killick hitch.—This hitch is begun by making a timber hitch, and completed by a half-hitch. (Pl. XXII, Fig. 5.) It is used for hauling and lifting spars, the half-hitch being placed near the end of the spar to be moved.

Stopper hitch.

Stopper hitch.—This hitch is made as follows :—Take one turn with the stopper round the cable towards the side on which it is wished to relieve the tension, and then a second turn over-riding the first. Pass the end of the stopper up between its standing part and the second turn, then over the standing part of the stopper down under the cable and round three or four times in the direction of the tension and the turns in the opposite direction to the original ones ; its end is then seized to the cable. (Pl. XXII, Figs. 6 and 7.) It is used for making a hitch that will not slip with one rope or chain on a second rope or spar. A gasket is useful for a stopper.

IV. Knots to make a loop on a rope.

Bowline.

Bowline.—A bowline is used for forming a loop that will not slip at the end of a rope. To make it, lay the forefinger of the right hand along and above the running end, hold the standing part away from the body with the left hand, back down ; lay the running end over and at right angles to the standing part just in front of the left hand ; turn the right hand over and outwards, bringing the forefinger up through the small loop which is formed on the standing part ; then holding this small loop with the left hand, pass the running end under the standing part and up again, and then down through the small loop and haul taut. (Pl. XXII, Figs. 8 and 9.)

Bowline on a bight.

To make a **bowline on a bight**, double the rope, and laying the bight—held in the right hand—over the two ends held in the left hand, start making a bowline as before. Then open out the doubled end, pass it over the whole of the knot and to the front again, but now under the two ends, taking care that the knot does not turn over ; then haul taut. (Pl. XXII, Fig. 10.) This is used for making a loop that will not slip in the middle of a rope.

Running bowline.

Running bowline.—A running bowline forms a loop which can easily be slipped along a spar and tightened at any point. To make it, pass the running end round the spar and take hold of it with both hands (the end in the right hand) as far apart as appears desirable, and so that the standing part passes over the running and between the hands. Then, with the end in the right

hand, tie a bowline on the running part near the left hand. The knot is then run through the loop. (Pl. XXII, Fig. 11.)

Lever hitch.

Lever hitch.—This is made as follows :—Make a loop with the rope, standing part uppermost, loop away from the body ; bring it round half-way across and over the standing part, then pass a lever or bar over the side of the loop under the standing part and haul taut. (Pl. XXII, Figs. 12 and 13.) It may be used with a lever to withdraw pickets, &c., or to secure the rounds of a rope ladder, or in connection with drag-ropes. A pair of drag-ropes at a convenient distance apart, with parallel bars secured by these knots, enable several men to pull abreast.

Man's harness hitch.

Man's harness hitch.—This hitch is begun like the lever hitch, but is completed by taking the side of the loop which is a continuation of the standing part, bringing it under the standing part and up between the standing part and the other side of the loop, and hauling taut. (Pl. XXIII, Fig. 1.) This forms a loop to pass over a man's shoulder to assist him in dragging on a rope.

Running knot.

Running knot.—This knot is formed by making a thumb knot with the running end round the standing part. (Pl. XXIII, Fig. 2.) This makes a loop that will draw taut round an object.

Slip knot.

Slip knot.—To make this knot, take a bight on the end of a rope and grasp it in the left hand, bight towards the left ; turn the running end back on the bight, take three turns with it round the three parts of the rope away from the bight, and pass the running end up through the small loop on the right and haul taut. (Pl. XXIII, Fig. 5.) This knot can be slipped over a spar and tightened up at will.

V. Knots for use with blocks.

Blackwall hitch.

Blackwall hitch.—This hitch is made as follows :—Make a half-hitch well up on the shank of the hook and haul taut, when the running end will be jammed against the curved part of the hook. (Pl. XXIII, Fig. 3.) This is used for fastening the end of a fall to the hook of a block ; it only holds while the stress is on.

Double Blackwall hitch.

Double Blackwall hitch is made by placing the rope against the top of the hook of the block at the front. The returns are then crossed at the back of the hook, and again inside the hook. (Pl. XXIII, Fig. 4.) This is much more secure than the single Blackwall.

Single sheet bend.

Single sheet bend.—This bend is a good mode of fastening the fall of a tackle to the ring or becket of a block, as this allows the blocks to come chock or close together. (Pl. XXIII, Fig. 3.)

Cat's-paw.

Cat's-paw.—A cat's-paw at the end of a rope is made as follows :—Take two equal bights, one in each hand, and roll them over the standing part till surrounded by three turns of the standing part, then hook the block into both loops. (Pl. XXIII, Figs. 6 and 7.) A cat's-paw in the middle of a rope is formed as follows :—Lay the rope across the palms of the hands turned upwards, turn the hands inwards and continue doing so until the

rope is twisted on itself two or three times by either hand, then bring the two loops thus formed together, and hook the blocks through them both. (Pl. XXIII, Fig. 8.)

Slinging a cask.

To sling a cask horizontally, form a bight at the end of the rope with a bowline, take a side of the bight in each hand (backs upwards), and give them a turn backs downwards, forming two loops. Pass the loops over the ends of the cask and haul taut. (Pl. XXIV, Fig. 1.)

To sling a cask vertically, lay the rope on the ground and place the cask on it about twice the length of the cask from the running end, then with both parts of the rope tie the first half of a reef knot on top of cask, open out and pass the loop thus formed over the head of the cask halfway down to the bung; adjust the sling and make fast the running end to the standing part of the rope with a bowline. (Pl. XXIV, Fig. 2.)

Belaying.

A cable is belayed to a cleat by taking a round turn round the cleat, and as many figure of eight turns as may be necessary. This may be finished off with a half-hitch on one arm of the cleat; but this should never be done if the cable may have to be cast off in a hurry, as in pontooning.

Splicing.

28. Cordage is sometimes united by splicing instead of by knots.

Eye splice.

To make an eye splice, unstrand a length of the end of the rope about two and a half times its circumference, and then bend the end down to the standing part, forming an eye of the required size, laying the middle strand on the top of the rope and forcing it from right to left under one of the strands of the standing part, having previously opened them with a marline spike. The left hand strand is then forced from right to left over one strand, and under the next on the left. Having turned the rope round to the left, so as to bring the right-hand strand on the top of all, force it from right to left under the strand of the rope immediately on the right of the one the first or middle strand was passed under. Each strand of the end is now passed in succession between the strands of the standing part, no two contiguous strands being passed under the same strand, and each strand of the end being taken alternately over and under the strands of the standing part. The strands are opened by means of a marline spike, at the same time twisting the rope in a direction opposite to its lay, thus causing the hole to keep open when the marline spike is withdrawn. The strands on being put through should be drawn taut. They should be worked in twice, then halved and worked in once, and then halved again and worked in to complete the splice. When the splice is complete, their ends are cut off and the splice beaten down with a wooden mallet. (Pl. XXIV, Figs. 3, 4 and 5.) An eye splice is nearly as strong a fastening as a bend with seizings, and stronger than a clove hitch.

Short splice.

To make a short splice, the ends of the two ropes to be spliced are unlaid and the strands are married—that is, the strands

of one rope placed between the strands of the opposite rope and drawn taut. The strands of one rope may then be seized to the other rope, while the splicing of the other strands is proceeded with by passing each strand from right to left over and under alternate strands in the opposite rope, in a similar way to that described for the eye splice. The strands of the other rope are then treated in the same way and the splice completed. (Pl. XXIV, Figs. 6 and 7.) Such splices have been found to be as strong as the rope.

Long splice.

A long splice is used when it is required to join up two ropes in such a way that they can still be rove through the same size block as before. This is effected by splicing each pair of strands at an interval of 2 or 3 feet from the other strands. Begin by unstranding the end of each rope for a length of 2 or 3 feet, according to the size of the rope (not less than seven times the circumference of the rope), and marry the two ends as described for the short splice, bringing the unstranded portions well against each other. Select a pair of strands (one from each rope) which come opposite to each other, and twist them loosely together so as to get them out of the way temporarily. Then begin unstranding one strand of one of the ropes, replacing it carefully by the corresponding strand of the other rope to 3 or 4 inches from its end. Twist these two ends together to get them out of the way also, and then unlay the remaining strand of the second rope and replace it by the remaining one of the first rope. Now untwist each of these last strands and divide them into two equal portions, one portion from each strand being cut off and the other two being tied in a thumb knot, so as to fill up the vacant space in the lay of the strands. These ends are then twice taken over one strand and below the next on each side of the knot and then cut off, and the whole dressed down with the mallet or marline spike. The other strands are then spliced in the same manner and the splice thus completed. (Pl. XXIV, Fig. 8.) It is found from experiment that a long splice is from 5 to 40 per cent. weaker than the rope.

In making splices which have not to run through a block, the ends of the strands should not be cut off close to the rope, but $\frac{1}{2}$ inch should be left projecting.

Iron and Steel Wire Rope.

Iron and steel wire rope.

29. Rope made of iron wire is not commonly met with now. In the case of steel wire rope the quality of the steel employed may vary considerably, and the strength of the resulting rope is also different.

Varieties of type.

The wire may be either galvanised or ungalvanised. All rope issued by Ordnance is galvanised and may be made up in several different ways, as follows :—

I. Iron or steel wire alone is used in making the rope. The core of each strand consists of an iron or steel wire, round which

the other wires are twisted. If the rope is composed of several strands, one would be placed at the centre of the rope, and the others twisted round it.

II. Strands composed entirely of wires as above are laid up round a hemp core.

III. Each strand contains a hemp core, and if the rope is composed of several strands one would be placed at the centre of the rope and the others twisted round it. This type of rope is not very common.

IV. Each strand contains a hemp core, and the rope is composed of several such strands laid up round a hemp core. This is the most usual type of rope.

Manufacture.

A "laid" rope consists of a heart composed of a strand of either hemp or wire, round which are twisted 6 strands, each composed of 6 wires round a heart.

A "formed" rope comprises 6 strands laid round a heart as above, but each strand contains a larger number of component wires—that is, for example, round the first 6 wires a further outside layer of 12 would be laid, thus making 18 wires in all independent of the core.

A "cable laid" rope consists of 6 laid ropes closed together to form one cable. Though this is more supple than the ordinary form of rope and lighter, it is decidedly weaker, and is not generally considered a good way of making up wire ropes.

Other arrangements of the wires are met with, but the above are the most common. As a rule the wires in any one rope are of the same size, though in ropes of some manufactures wires of two or more gauges are employed.

The flexibility of wire ropes is principally dependent upon the multiplication of their component wires, and the manner in which they are laid. It is comparatively easy to make a rope containing only a few wires, but it requires considerable skill and experience as the number increases to arrange the wires and their lays, so that each component wire shall bear its due and proportionate amount of working stress. Hemp cores produce a more flexible rope, but naturally a weaker one for the same diameter. It is usual to steep the hemp in hot linseed or other vegetable oil. This weakens the hemp, but the presence of any acid is highly detrimental to the life of a wire rope.

Improvised wire ropes.

30. Wire ropes to be used for the cables of suspension bridges are sometimes built up of wires stretched and lashed in bundles. The essential point in making them up is to give all the component wires the same strain while they are being bound together. If this point is not carefully looked to, some of the component wires, when the cable is loaded, will be more stressed than the others, and consequently will be liable to fail before the resistance of the others has been developed. This method of making up cables has the advantage that the wire can be made up in coils of no greater weight than a man can carry thus simplifying this question of transport in difficult country.

The following method can be employed in making up the cables in the field :—All the wire must be properly unrolled by two men taking each coil, attaching one end to a tree or holdfast, and rolling the coil along the ground away from the tree. This is necessary, for if the wire is merely pulled off from one face of a coil there will be one twist in each length equal to the circumference of the coil, producing kinks, with corresponding weakness, when the wire is stretched.

To construct the cable, seven of the unrolled wires must be attached to a tree or other holdfast, and another holdfast made at a distance equal to the required length of the cable. With picket holdfasts, precautions must be taken that the top of the picket does not move forward under the stress ; if it does, the first wires placed will become loose and the strength of the cable much diminished. A rope should now be attached to the free end of one of the wires, and when the wire has been stretched as tightly as possible by a suitable number of men hauling on the rope, it must be made fast to the second holdfast by walking round it a couple of times, keeping the strain on. The other wires must be stretched and secured in a similar way, the same strain being kept in each by using the same number of men to pull each time, if necessary with the addition of a spring balance.

Now, beginning at the first holdfast, the 7 wires must be bound together into a group with bindings of twine or thin wire at intervals of 9 inches to 1 foot. The wires should not be allowed to override anywhere, and for this purpose a rough gauge of wire twisted into loops can be used and run along as the binding progresses, thus keeping each wire in its proper relative position.

The requisite number of bundles of 7 wires can be subsequently bound into one cable in a similar way, the bindings being made of wire and put on at a greater interval.

The following is another method which has given very good results :—

An anchorage A is set up, and to it attached a pulley block B and a picket C, 3 or 4 feet long. (Pl. XXVI, Fig. 3.)

The wires are laid out along the ground clear of each other and the end of each is attached to one of the small pulley blocks E. The ends are passed through the holes in the template D and made fast to the block B.

The template D (Fig. 5) can be readily made out of 1-inch wood. Any wood will do, but hard wood is preferable. A foot square is large enough, and the holes should be bored symmetrically in the form of a hexagon with one hole in the centre for the core wire. The holes should be on a circle of about 8 inches diameter.

The pulley blocks E are each held by one man who lays back on his wire and keeps an even strain on it. It is most important that the wires be strained equally. The slackening of any wire

during the process of twisting will at once produce an uneven piece of rope.

The men should be evenly spaced from 2 to 5 paces apart, according to the length of rope to be made, and it is a good plan to attach the blocks to the men's belts or round their waists with spun yarn, so that by leaning back a steady strain may be kept up without fatigue.

Two men twist on the picket C, and two men hold the template at right angles to the centre wire. The template should be about 18 inches from the hook of block B at the start, and is moved slowly back as the rope lays up, being kept from twisting and at about 18 inches from the point where the wires come together. If the template is allowed to twist even slightly during the formation of the rope, a faulty lay at once results.

The swivels of the pulley blocks E should be well oiled so that the twist in each wire may be taken out, and the men should occasionally give the blocks a turn to make sure that the friction of the swivel has not allowed the wire to twist. This is particularly necessary in the case of the centre wire, and it is a good plan for the man in charge of this wire to turn his block by hand, taking the time from the men twisting at the other end, to ensure that the centre wire is laid up in the rope quite straight.

The template shown in Fig. 5 can be used to lay up 3 wires together, using, of course, alternate holes only and omitting the centre hole.

For a 19-strand, or 37-strand, cable a larger template must be used, as in Fig. 4.

The holes are bored for each layer in the form of a hexagon, spaced equally apart as the wires will lie when laid up in rope. The practical difficulty of finding enough pulley blocks, or a large enough template, will usually preclude the laying up of more than a 19-strand cable in one operation, and in this case the third layer may be put on separately. The template for the third layer need not be larger than that for the second layer so long as the holes are correctly placed, and the central hole is large enough for the 19-strand cable.

The same practical difficulty will usually limit the number of layers to three, but larger cable can be made by laying up 3-strand or 7-strand cable instead of single wires.

When using wire of No. 8 gauge, or thicker, the swivel blocks E will turn automatically, and economy of the working party can be effected by the following arrangement. For a 7-strand rope four pickets are driven (Pl. XXVI, Fig. 6), and the six blocks are attached to these by means of a single rope which passes alternately through the swivel blocks and behind a picket as shown. The six blocks to which the outside strands of wire are attached are best arranged in two rows of 3, while the strand which is to form the core is attached to a seventh block, which is separately attached to the pickets. This block must be turned

by hand. All the wires can be strained evenly by means of the continuous rope attachment, and only one man is required at this end to turn the core swivel and to generally manage the other six blocks.

This arrangement has the further advantage that the wires are not so widely spread apart as when held by men, and this makes the movement of the template along the wires easier. The template for use with thick wires should be of very hard wood, and, if possible, the holes should be metal lined.

It has been found that the strength of ropes laid up by this method is practically equal to the total strength of the number of strands in the rope less those forming the core. Actually it is slightly greater, but the core does not contribute its full share of strength and should not be considered in calculations. In large cables it would therefore be more economical of material to use old hemp rope or some other material for the core.

31. It is usual to take the weight of wire rope as equal to C^2 lbs. per fathom, C being the circumference in inches. This is approximately correct; but the real weight varies with the relative proportion of hemp core in the rope, this expression giving too high a value when there are hemp cores in the strands as well as in the rope itself. Weight of wire rope.

32. The strength of wire ropes depends upon a great number of factors. As in the case of cordage, the breaking and the working stresses are expressed in terms of a load per circumference squared. Strength of wire ropes.

The material of which the ropes are made is the principal factor. The breaking stress of special "agricultural" steel wire ropes may vary from 3 C^2 tons to 4 C^2 tons; that of ordinary steel wire ropes, from 2 C^2 tons to 3 C^2 tons; and that of iron wire rope and very mild steel wire rope from C^2 tons to 2 C^2 tons. A very common mistake is to assume that any steel wire rope that is about to be used is made of the special "agricultural" steel wire, and its strength calculated accordingly. As a matter of fact, such wire ropes would only be found in cases where lightness is so essential that the considerable increase of cost would have to be disregarded.

Another important factor is the material of which the various cores, both main and strand, are made. Hemp cores add practically nothing towards the strength of the rope, and the chief consideration is consequently the ratio that the total area of the wires bears to the area of the rope. The variation of this ratio is shown by the following average results for galvanized wire ropes of three different types :—

	Ratio of wire area to total.	Comparative strength.
Wire cores	·55	1·8
Hemp main core	·46	1·5
Hemp main and strand cores ...	·30	1

With ropes containing a hemp core the larger sizes are stronger in proportion, as the proportional area of the hemp core is less.

The lay or arrangement of the wires also affects the strength of the rope. Generally speaking, a rope made up of a considerable number of wires is stronger for the same circumference than a rope made up of a smaller number of larger wires. On the other hand, ropes made of wires of several different sizes are generally weaker.

Galvanized wire ropes are on the average about 5 to 10 per cent. weaker than ungalvanized ropes of the same circumference, due to the fact that the wire is increased in diameter by the process without being increased in strength.

Table L (p. 81) gives some experimental results, but as no information is available as to the varying qualities of the wire used in making the ropes, the figures lose a good deal of their value.

Working stress.

To obtain the safe working loads, a factor of safety must be applied to these breaking loads. In the case of new ropes this should not be less than 3, and in the case of old ropes 4.

Taking the breaking load of the rope usually supplied by Ordnance as $1 \cdot 75\ C^2$ tons, and using a factor of safety of 4, the following rule for use in the field is obtained :—

$$\text{Working load} = \frac{7}{16} C^2 \text{ tons.}$$

The following is practically identical :—

$$\text{Working load} = 9\ C^2 \text{ cwts.}$$

For ropes made of special quality steel or in cases where the cores are made of wire, these figures can be correspondingly increased.

Strength of wire.

33. In case it is required to make up cables out of bundles of wire, the figures as to their strength given in Table M (p. 82) may be useful; they are derived from a considerable number of experiments. These figures will give an idea of the breaking stress of a wire when its gauge, and consequently its area, is known.

A factor of safety of at least 3 or 4 must be used in the case of a cable built up of wires, to allow for the fact that several of the wires will probably be taking more than their share of the load. A rough rule for iron wires, giving a factor of safety of about 3 or 4, is :—

Working load = weight of wire in lbs. per mile.

For steel wire, about twice this might be used.

Stretching of wire ropes.

34. The extension of wire ropes up to about one-quarter of the breaking load is, approximately, proportional to the stress. From this point up to about half the breaking load it begins to get rather more than proportional. Beyond this point again it rapidly increases up to the point of breaking. The nature of this extension shows that a factor of safety of at least 4 should

always be used if possible, to avoid the risk of getting beyond the elastic limit.

The actual amount of the extension varies to a certain extent with individual ropes; but approximate rules for it, up to about one-quarter or one-third of the breaking load, are as follows:—

Wire core ropes	$\cdot 25 \frac{S}{C^2}$	Percentage elongation of original length.
Hemp main core	$\cdot 3 \frac{S}{C^2}$	
Hemp main and strand cores ...	$\cdot 5 \frac{S}{C^2}$	

where S is the load in tons and C the circumference in inches.

35. Wire rope should not be worked round sheaves or barrels of too small a diameter, as this would bring an unfair proportion of stress on some of the wires. As a rough rule the diameter of the sheave, &c., should not be less than six times the circumference of the rope. The diameter of any holdfast round which a wire rope may be secured should not be less than four times the circumference of the rope. Practical points.

Small wire ropes may be coiled like cordage. It is often convenient to coil them on a drum. Large wire ropes should be coiled in a figure of eight, which allows of their being uncoiled without kinking.

Wire rope should be kept well oiled, linseed oil being the best for the purpose. This should be done at least once every two or three months.

Before cutting a wire rope, it should be seized on either side of the proposed cut with spunyarn; it is also advisable to seize the ends of all wire ropes.

The majority of knots required for cordage are applicable to wire ropes, avoiding those varieties where the rope would have to be bent sharply.

The running end of a wire rope may be seized to the standing part as follows:—Seize the running end of the rope strongly to the standing part with tarred yarn nearly up to the extremity of the running end. The wires of this end are then opened out, bent back over the seizing, and a fresh seizing passed round them and the standing part, so that they form a plug.

36. Wire ropes may be spliced in a somewhat similar way to cordage. Splicing wire ropes.

The apparatus required for eye splicing wire ropes consists of a wooden block about 6 feet by 1 foot 6 inches by 1 foot 3 inches, fixed to two supports 1 foot 6 inches by 9 inches by 9 inches. (Pl. XXV, Fig. 1.) The block is perforated with four rows of holes, each row containing four holes, the outer rows being 6 inches and the inner row 1 foot 6 inches from the ends. The holes are $2\frac{1}{2}$ inches in diameter and 1 foot deep, and their tops are strengthened by plates of iron 4 inches by $\frac{1}{2}$ inch, having Eye splice.

corresponding holes cut in them. A few crowbars and small pinching-bars are also necessary. With small eyes thimbles should always be used. An eye splice is made as follows :—Mark on the rope with a piece of spunyarn the place where the splice is to begin. This distance is determined by measuring the outside of the thimble, and adding the circumference of the rope and 3 feet (the amount of rope which is convenient to unstrand) this gives the point required. A piece of spunyarn should also be tied round the rope 3 feet from the end; then place a crowbar (A) in one of the centre holes of the outside plate and pass the thimble over the crowbar, and bend the rope round it as taut as possible. This is done by securing two lashings (C, D) by means of stopper hitches to the standing and running ends of the rope, placing two crowbars (E) at the other end of the block, and taking a bight of each lashing two or three times round them, windlassing them up by placing small pinching-bars (F) in the loops formed by the bights. After it has been drawn perfectly taut, the ends of the pinching-bars should rest against one of the crowbars at that end of the block to prevent them from slipping. When the wire rope is taut take two or three turns with a lashing round both parts of the rope a little below the point of the thimble and place a pinching-bar (G, G) on the ropes over the turns, then take two or three turns with a bight of each end of this lashing round the bar, after which pass a small bar (H) through each loop formed by the bights, and using these bars as levers twist up until the rope fits close to the thimble. (Pl. XXV, Fig. 3.) Lash the ends of these small bars to crowbars (K, K), place one on each side of the one over which the thimble has been placed or to the standing part of the rope, to prevent them untwisting. Then seize with spunyarn the two ropes at the place where they meet at the point of the thimble, and also seize the thimble to the rope in two places, about 2 or 3 inches from the point of the thimble. (Pl. XXV, Fig. 4.) Having brought the rope to the shape of the thimble and secured the thimble to it as above, take the stress off the rope by removing the lashings C, D, and levers F, unstrand the running end of the rope, remove the core, whip the end of each strand and proceed with the splice as follows :—Raise with the marline spike a convenient strand of the standing part of the rope, and pass under it the right hand strand of the running end, draw it through, pulling it taut, lay it along the rope, and lash it down so as to prevent it flying back. Then raise the next strand to the left of the last one on the standing part, and place under it the next strand to the left of the running end, draw taut, and lash down as described for the first one, and proceed in this order until a round is complete—each round when complete should be served with spunyarn to prevent it from springing back. Then remove the core from each strand and complete a second round in the same manner, after which

reduce the size of the strands by one half, and complete a third round again, reduce the remaining part of the strand by one-half, and complete the fourth round, cut off the ends of the strands, and complete the splice by hammering it well down and serving it over with spunyarn by means of a serving mallet. (Pl. XXV, Fig. 2.)

To make a short splice, the ends of the two ropes to be spliced are unlaid for a length of 1 foot 6 inches to 3 feet, according to the size of rope, and are then married. The left rope should be served with spunyarn to prevent strands from unstranding. The strands of the right rope are laid along and seized to the standing part of the left rope, while the strands on the left rope are being spliced into that of the right, which is done in the same manner as in the eye splice. The strands of the right rope are then cast loose, and the seizing on the left removed, and the splicing of that part completed in the same manner. Short splice. Wire rope.

To make a long splice, unstrand the two ropes for about 4 or 6 feet (according to the circumference of the rope) and then seize with spunyarn at that point, one strand of one of the ropes being left free. The end of each strand is whipped. They are then married in the ordinary way and tightly seized with spunyarn over the centre of the joint. Then unlay the strand left out, and replace it by the corresponding strand of the other rope up to a convenient distance, so as to allow the remaining strands to be worked in, which is done in a similar manner, working alternately right and left, and finishing off each pair of strands before proceeding to the next. The splice is finished off as follows:—Having replaced one strand by another, as stated above, the cores of both strands are removed. The strands are then crossed and passed under the adjacent strands of the rope; the strands are then halved and passed over one strand and under the next; the ends are then cut off and completed. The jointing of all but the first two pairs of strands must be so arranged as to have the joints as nearly as possible at equal distances from one another, between the two first or outer ones. After the first pair of strands is completed the seizing is cut away. Long splice. Wire rope.

Chain.

37. Chain is identified by the diameter of the iron forming the link, and may be— Varieties of chain.

(1) Short-link or crane chain.
(2) Long-link or cable chain.
(3) Studded chain.

Long-link chain is weaker than either of the others, and is not now issued for military purposes.

Each link of short-link chain has a length equal to five times the diameter of the iron used for the links, and studded chain has a length of six times this diameter. Any chain over five

diameters in length and not studded is called long-link chain. Both short-link and studded chain have a width of three and a-half times the diameter of the iron.

Chain is issued in various lengths according to the work to be done, and is measured in fathoms.

The smaller sizes of short-link chain are usually galvanised. Studded chain is usually ungalvanised.

Weight of chain.

According to Government specifications, the weight of chain from which a variation of 5 per cent. is allowed, is approximately given by the following rough rule :—

Short-link chain	$64\ d^2$ lbs. per fathom.
Studded chain	$59\ d^2$,, ,,

where d is the diameter of the iron in inches.

Strength of chain

According to Government specifications, a short piece of each chain supplied is tested with a load that may be taken as the equivalent of the breaking stress. The amount of this load is given by the following rules :—

Short-link chain	$24\ d^2$ tons.
Studded chain	$27\ d^2$,,

In the case of short-link chain this is equivalent to a stress of about 15·3 tons per square inch, whereas the iron from which the chain is made is specified to have a tensile strength of 23 tons per square inch. This difference is due to the way in which chain fails, namely, by the links distorting and pulling out. This also shows why studded chain—though lighter—is stronger, as it is helped against this distortion by the studs.

Proof load.

In addition to this test load, the whole chain is subjected to a proof load, which is half the test load for a short-link chain and two-thirds the test load for studded chain, namely :—

Short-link chain	$12\ d^2$ tons.
Studded chain	$18\ d^2$,,

On an emergency new chain may be used up to the proof stress, but for ordinary use half this amount should not be exceeded. Even this, in the case of studded chain, does not give a very large factor of safety.

Long-link chain is only about five-sixths of the strength of short-link chain made from the same iron—that is, its test strength would be about $20\ d^2$ tons.

Working load.

33. For use in the field, the following rules may be used to give the safe working load :—

Short-link chain	$6\ d^2$ tons.
Studded chain	$7\ d^2$,,
Long-link chain	$5\ d^2$,,

Annealing chain.

When chain has been subjected to violent use, such as loads coming on suddenly, the iron of the links becomes crystalline and brittle. Chains used for such purposes should be annealed

periodically, to restore the iron to its fibrous condition. This may be done by heating it to a very dull red heat and then allowing it to cool slowly.

Shackles.

39. Chains are generally connected by shackles. The best pattern is the screw shackle, and is that generally used with chain whenever it is desired to connect or disconnect quickly. All screw shackles should be tightly screwed up with a marline spike, and if intended to remain for any length of time, should be wired—that is, the eye of the pin should be lashed to the bow with a few turns of wire. Another pattern of shackle met with has a plain pin with a slot, and a split pin. If often opened and closed the split pin is apt to break.

Strength of shackles, &c.

The strength of the service pattern shackle is about three-quarters of the strength of short-link chain made from the same diameter iron. It will be seen that the shackles used for any chain must, for equal strength, be of larger diameter metal than the chain, and thus will not fit easily in the end link. It is therefore usual to fit each end of a chain with a special large link, called a "long link," into which the shackle can be fastened. To get equal strength, the metal in the long link should be one-sixth stronger than that used in the rest of the chain. This is done in practice by making the long link of metal $\frac{1}{8}$ inch thicker than that used in the chain. Thus $\frac{7}{16}$-inch chain should have long links of $\frac{1}{2}$-inch metal and $\frac{5}{8}$ inch shackles.

Eye bolts and hooks.

40. Eye-bolts are about six-sevenths and triangular and circular ring-bolts are about one-third as strong as short-link chain of the same diameter iron. For field use it would be near enough to take their safe working loads as follows :—

Eye-bolts	$5\ d^2$ tons.
Triangular and ring-bolts	$2\ d^2$,,

where d is the diameter of the iron as before.

Hooks are about one-ninth as strong as short-link chain of the same diameter iron. They are seldom, however, made of the same diameter iron throughout, but are specially shaped to have more metal at the point where the stress is greatest—that is, at the back of the hook. It is this largest dimension that must be considered when calculating their strength. For field purposes the working load on hooks can be taken as $0 \cdot 7\ d^2$ tons in the case of a plain hook, and $0 \cdot 5\ t^2$ tons in the case of a shaped hook, where t is the greatest dimension at the back of the hook.

Joints and Fastenings.

Classification of joints.

41. Joints are used for the following purposes :

For lengthening ties or beams in tension.
,, ,, struts or beams in compression.
,, ,, beams under transverse stress.
,, beams bearing on beams.

For beams on posts.
,, posts on beams.
,, connecting struts with ties.
,, between struts and beams.
,, between ties and beams.

Principles of joints.

The principles which govern the design of joints and fastenings are as follows :—

(1) Joints should be cut and fastenings arranged so that the members which are connected are weakened as little as possible.
(2) Each part of a joint should be proportional to the stress it has to bear, and every pair of surfaces in contact should be fitted accurately, in order to distribute the stress uniformly.
(3) Fastenings should be so designed as to be of equal strength with the members which they connect.
(4) Joints should be planned so that the stresses are uniformly transmitted from one member to the other.
(5) Joints should be arranged so that they are affected as little as possible by expansion or contraction of the materials.
(6) Abutting surfaces in compression should be placed as nearly as possible at right angles to the direction of the pressure coming on them, so as to avoid resolved stresses in other directions.
(7) With timber joints the fastenings in each member should be placed so that there shall be sufficient material to resist the crushing or shearing of the fastenings which pass through it.

Classification of fastenings.

Fastenings are used for making joints more secure, and may be classified as follows :—

(1) Bolts and nuts.
(2) Straps.
(3) Rivets.
(4) Nails, spikes and drift-bolts.
(5) Screws and coach screws.
(6) Trenails.
(7) Dogs.
(8) Lashings.

Framed joints.

Unless skilled labour is available, all complicated construction in framed joints, such as mortice and tenon work, should be avoided as far as possible, the members being made to butt square. The fastenings employed should be such as are most readily obtained and used. Bolts and nuts make good fastenings, but fixing them takes time. Nails, spikes, trenails and dogs are of great utility. Lashings should only be used if nothing else is available.

A lapped joint consists in simply laying one beam over the other for a certain length, and binding them together with straps or bolts. (Pl. XXVII, Fig. 1.) This joint is clumsy in appearance, but is stronger than those of a more artificial construction. Lapped joints.

In a fished joint the ends of the members are butted together, and an iron or wooden plate or fish-piece is fastened on each side of the joint by bolts passing through the beam. (Pl. XXVII, Fig. 2.) The bolts should be placed chequerwise, so that the fish-plates and timbers are not cut through by more than one bolt-hole at any cross section. Fished joints.

When subjected to tension the bolts are apt to press upon and crush the fibres, thus causing the joint to yield. The joint is helped by the friction between the beam and the fish-plates, but when the timber shrinks this friction is removed.

When a beam is fished to resist compression, there should be plates on all the four sides.

A fished joint is not very suitable for a beam under transverse load, but the principle is sometimes made use of in constructing composite spars. The various spars must be arranged to break joint throughout, and carefully lashed at every 5 feet, the lashings being wedged up. A similar method can be employed when single spars of the required lengths for the frames of bridges cannot be obtained; short ones can be fished together. (Pl. XXVII, Fig. 3.) Beams treated in this manner have been used for road-bearers, and have been found to be nearly as strong as single pieces, provided the cover piece has the same section as the beams, is over half the length of the spar and is well lashed.

Cover-plates or fish-plates should be used with iron girders—employed as road-bearers—to connect them where they butt against one another over a trestle or abutment.

In a scarf joint the members are cut to fit one another, so that the resulting beam is of the same thickness throughout. Pl. XXVII, Fig. 4, shows a scarf joint adapted to resist compression; the bearing surfaces are large and perpendicular to the compression. Under a tensile stress it would depend entirely upon the shearing strength of the bolts to hold it together. Fig. 5 shows a scarf joint for beams in tension; and Fig. 6 shows a beam scarfed vertically through its depth to resist transverse stress. Scarf joints.

For tension members some form of adjustable joint is often useful. This can be obtained conveniently by the use of coupling boxes or some similar arrangement with reverse screws, which enable the member to be tautened while in position. Adjustable joints.

Pl. XXVII, Fig. 7, shows a halved joint; Fig. 8 shows a notched joint; Fig. 9 shows a cogged joint; and Fig. 10 shows a tusk tenon. Beams on beams.

Fig. 11 shows how a post can be housed in a beam; and Fig. 12 shows a mortice and tenon. Posts and beams.

Ties and struts.

Fig. 13 shows the use of plates in connecting tension and compression members. A modification of the same principle can be used with timber members. Pl. XXVIII, Figs. 1 and 2, show another method of uniting such members, and also illustrates the use of hard wood blocks.

Cleats.

In place of cutting away the material of one member, a plain or butt joint can often be made nearly as good by the use of cleats. (Pl. XXVIII, Fig. 3.) An adaptation of this principle to the joint between the legs and transom of a trestle is shown in Fig. 4.

Bolts and nuts.

42. Bolts are often used to give additional security to joints, some forms of which, indeed, depend upon them altogether for strength. They have the disadvantage of weakening the beams through which they pass by cutting the fibres. If the timber shrinks they become loose and bruise the grain of the wood where they bear upon it. Square bolts, with one side at right angles to the pressure upon them, have been found by experiment to cut less into the timber than round bolts.

In many cases bolts are most useful, from the facility with which they can be tightened up by means of a screw and nut after the work in which they are used has taken its bearing. One end of the bolt is generally formed into a solid head and the other with a screw, on which is fixed a movable nut.

The size of bolts should be calculated according to the stresses upon them and the quality of the iron used; their bearing stress upon the fibres of the beam in which they are used must also be considered. Care must also be taken that sufficient timber is left round them to prevent their shearing the timber in the direction of the stress.

The following proportions will be found suitable for bolts:—

Diameter of head and nut ...	$1\frac{3}{4}$ ×	diameter of bolt.
Thickness of head	$\frac{3}{4}$ ×	,, ,,
Depth of nut	1 ×	,, ,,

Washers.

Washers are flat discs of iron placed under the head and nut of a bolt to prevent them pressing into and injuring the timber. For soft wood they should be three and a-half times the diameter of the bolt, and for hard wood they may be two and a-half times this diameter. Their thickness should be from one-quarter to one-half the diameter of the bolt.

43. Straps are often used instead of bolts to strengthen or form joints. They have the great advantage of not cutting through and weakening the timber. They are generally flat pieces of iron, about $1\frac{1}{2}$ to 2 inches in breadth, and with a thickness depending upon the quality of the iron and the stress upon them.

Straps should be fixed as nearly as possible so that the stress may come upon them in the direction of their length. Pl. XXVIII, Figs. 5 and 6, show two examples of strapped joints.

44. Rivets would not commonly be used for joints in the field, and when used would require skilled labour; but the same principles which govern the design of riveted joints are employed in nailed joints between plank members, a very useful form of construction. Rivets.

In such joints careful attention must be paid to the arrangement, so as to secure uniformity of stress throughout the whole of the joint, and uniformity of transmission to the members which the joint unites. To secure this uniformity it is essential to avoid eccentricity of stress transmission.

In the case of joints connecting members under compression and butting against one another, it is not safe to rely on the members being so closely butted together as to transmit the stress direct, and the joint should therefore be designed of sufficient strength to take the whole stress if necessary through the rivets or nails.

The great advantage of riveted or nailed joints is that the failure of one rivet or nail will not necessarily mean the failure of the whole joint, as it would in the case of a bolted joint.

Single riveting consists of a single row of rivets at right angles to the line of the stress, uniting plates in any form of joint. In double, treble and quadruple riveting there are two, three or four rows respectively. In the case of the last three the joint may be chain riveted—that is, formed by lines of rivets in the direction of the stress, parallel to one another on each side of the joint; or zigzag riveted—that is, lines of rivets so placed that the rivets in each line divide the spaces between the rivets in the adjacent lines. (Pl. XXVIII, Figs. 7 and 8.)

45. The employment of nails as fastenings has been mentioned in the preceding paragraph. A great many varieties of nails are in use, the more common of which, with the number in 1 lb., are shown in Table N (p. 82). (*See also* Table O, p. 83.) Nails.

46. Spikes are a large variety of nails, generally from 5 to 10 inches long. They would be used with heavier timbers for which nails would not be suitable. They may also be used singly in smaller work instead of bolts. Spikes.

When driven through planks which act as ties, the spikes should not be closer to the ends than from 12 to 18 inches, and the heads should not be driven into the surface of the wood. Chisel-pointed spikes should be driven so that the edge is across the grain.

A better spike is made by flattening part of the shank and then twisting it into a spiral when hot. This, if driven into an auger hole rather smaller than itself, holds well. The best augers for use, particularly for boring with the grain, are the bull-nosed augers. Great care is required in sharpening the augers used with iron fastenings, so as not to diminish the diameter close to the base where the cutting edges are, for if so diminished the cutting edges do not make a hole large enough to let the larger parts of the auger follow.

The weight of spikes is given in Table N (p. 82). (*See also* Table O, p. 83.)

Drift-bolts.

47. Drift-bolts are long iron spikes with a point at one end and a head at the other. They are used for securing heavy timbers together, as in a trestle for a railway bridge. An auger hole slightly smaller than the bolt should be bored for them through the first piece of timber, which would generally be against the grain; but they will force their own way into the second piece, generally with the grain.

Screws.

48. Screws are useful when the work may afterwards have to be taken to pieces, in cases where driving a nail might split the timber, for fixing ironwork, and in other cases where security is required without jarring the joint.

Screws securing work likely to be removed should, if used in damp places, be of copper or brass, otherwise they will rust and be difficult to withdraw; or some non-acid grease may be put upon the screws before driving them.

Coach screws.

49. Coach screws are large heavy screws used where great strength is required in heavy woodwork, and for fixing iron work to timber. They have square heads, so that they can be screwed home with a spanner or wrench; but they are frequently merely driven with a hammer. (Table N, p. 82.)

Trenails.

50. Trenails are wooden pins, and are made of hard wood, used in a similar manner to nails and spikes. They are useful in cases where iron nails might rust or when they are not available.

They should be cleft from the log if possible, to avoid cutting into the longitudinal fibres. They can also be made by preparing them roughly and then driving them through a nut or die-plate to shape them. The best section, however, is square or polygonal.

An auger hole must be made for them, and it is customary to drive a square trenail in a circular hole, the diameter of the circle being equal to or a little larger than the side of the square. By putting one sledge hammer against the trenail head and striking this hammer with a second one, a trenail can be driven without being split. If a longitudinal saw cut be made in the outer end of the trenail when the latter is in place, a thin wedge can be driven into the cut to tighten it.

The average ultimate resistance to shearing per square inch of section for hard wood (oak, ash and beech) trenails has been found to be about 2,000 lbs.; for soft wood, from 1,000 to 1,200 lbs. Trenails of large diameter—2 inches and over—are found to be stronger per square inch of section than smaller ones and should be used in preference.

Dogs.

51. Dogs are generally from 9 to 18 inches long and the teeth from 3 to 8 inches long; the service patterns are 12 and 15 inches long, with 6-inch teeth. They are made of iron of section from ½ to 1 inch, a square section being best. To get the greatest holding power, the spikes should have a length of from ten to twelve times the diameter or side of the iron.

They are used for fastening frames of heavy timber, and the position of each must be chosen with the definite object of preventing a possible distortion of the frame; they must be on both sides of the frame. The teeth must not be driven within 3 inches of the edge or 4 inches of the end of a piece of timber. It is usual to bore an auger hole for the teeth of a dog slightly smaller than the section of the iron.

For straight dogs, the ends of the teeth should be slightly further apart than at their root. This causes the dog to draw the two pieces of timber together when driven. This drawing action must not be overdone on the first side of the frame to be dogged, otherwise when it is turned over it will be found impossible to draw the other edges together, thus leaving a gaping joint.

Dogs when heated red hot can be twisted till their teeth make any required angle with each other, generally a right angle; they are then known as skew dogs. It is important that skew dogs should be of the proper form and section, otherwise they cannot be driven securely. One tooth should be straight in shape and round in section, and should be driven first; the other tooth may be square in section and in form must be an arc of a circle struck from the root of the first tooth. (Pl. XXIX, Fig. 2A.) The weight of dogs is given in Table N (p. 82).

52. Two parts of a wire rope or cable may be secured to one another by clips made of wrought iron, shown in Pl. XXIX, Figs. 1 and 2. The ropes are placed in the clips and the wedges squeezed in between them. The cup is then placed over the lower rope, the bottom plate put on, and the whole screwed up by means of the nuts, after which the wedges are jammed by means of the outer screws. Fastenings for wire ropes.

Simpler forms of clips will often be sufficient when the stress to be transmitted is small.

A wire rope may be secured to another type of member as follows:—A conical-shaped hole is made in the latter, through which the wire rope is passed; the strands are then opened out and a cast-iron plug driven in. The joint is finished by running the interstices with lead. (Pl. XXIX, Fig. 3.) If an alloy of antimony and lead is used the plug can be omitted, the ends of the wires being turned over into hooks at the ends.

53. Lashings can be made of cordage, wire, wire rope and chain. Certain forms of creepers can be used as improvised substitutes. Lashings.

Cordage contracts and stretches according to the degree of moisture it contains, and therefore does not make a reliable joint for any length of time, especially in water work. It is also liable to rot. Wire, wire rope and chain are more difficult to apply, but are more permanent. With wire lashings it is better to twist three parts of the wire together and then use this for the lashing. Much time is saved by this, as only one-third of the

turns are required; and the lashings are considerably stronger, as it is found with lashings of single wire that only the top returns take the strain at first, and until these snap the lower ones do no work.

Wedges with well-rounded points are often used for tightening lashings. They should be driven so that their points may be downwards, to prevent their dropping out. Wire lashings may be tightened by twisting the returns with a long nail where they pass from one member to the other. This nail can be then driven into one member.

Square lashing.

To lash two spars which cross one another, a square or transom lashing is generally used. (Pl. XXIX, Fig. 4.) A clove hitch is made round one spar (A), the lashing brought under the second spar (B) up in front of (A), down behind (B), up in front of (A) again, above the clove hitch, and so on, following round, keeping outside the previous turns on one spar and inside those on the other, so as not to ride over the turns already made. Four turns or more will be required. A couple of frapping turns are then taken between the spars round the lashing, binding the whole firmly together, and the lashing is finished off at once with two half hitches round one of the spars. Any spare end may afterwards be got rid of by winding it round one of the spars. The lashing must be well beaten with a stick to tighten it up while the frapping turns are being put on.

When the spars to be lashed together are the leg and transom —that is, the vertical and horizontal spars—of a trestle or frame, the clove hitch with which the lashing is begun should be put on to the leg below the transom. The turns of the lashing will then come outside previous ones on the transom and inside on the leg. The two half hitches which end the lashing should be on the transom outside the leg, so as not to be in the way of the road-bearers. Any spare end of rope should then be twisted round the transom and secured with one or more half hitches.

The safe holding power of a square lashing can be taken as equal to four-fifths of the safe stress in the rope itself, multiplied by the total number of returns, of which there are four for every complete turn in the lashing. The fraction four-fifths is adopted to allow for the fact that it is not possible to get an equal strain in all the turns, and some will therefore bear a larger proportion of stress than others. With wire lashings it is still more difficult to equalize the strains, and the fraction is taken as three-fifths. In the lashings of trestles erected in muddy places care must be taken to prevent the lashing slipping on the leg, as the mud acts as a lubricant.

Double lashing.

If it is required to lash two spars to a third—as, for example, a double transom to a leg—a modification of the square lashing can be used. Begin by a clove hitch round the leg below the transoms, take a turn round both transoms and round the leg below the clove hitch; then take a turn round both transoms

on the other side of the leg; then take three partial turns round the leg and one transom, then a turn round both transoms, then three partial turns round the leg and the other transom, then a turn round both transoms on the other side of the leg, and so on, till sufficient turns have been taken. The turns should be outside those previously taken on the leg and inside on the transoms. Two frapping turns are then taken between the leg and each transom, and the lashing finished off in the usual way on one of the transoms.

Diagonal lashing.

To lash two spars which require to be pulled by the lashing into contact with one another—for example, the diagonals of a lashing or frame—a diagonal lashing is used. A running bowline or timber hitch is put diagonally round both of the spars where they cross and hauled taut. Two turns are taken round besides this knot and then three turns across the other diagonal. Two frapping turns are put on, and the lashing is finished off with two half hitches round one of the spars, the loose end being disposed of as before. In the case of a trestle the spare end should be wound upwards on one of the spars to prevent it slipping down. (Pl. XXIX, Fig. 5.)

Rack lashing.

A rack lashing is used to fasten ribands, and consists of an 8-foot length of 2-inch rope, with a short stick at one end. Standing on the platform or roadway the point of the lashing is passed down between two chesses, under the road-bearer, over the riband and twice round itself 1 foot from the stick, so as to form a bight. The point of the stick is passed through the bight of the rope, and the stick is twisted round from left to right (against the hands of a watch) till the lashing is tight. Its point is then turned downwards and forced in between the lashing and the outside of the riband from right to left. (Pl. XXIX, Fig. 6.)

A small rack lashing may be used to stopper or rack the returns of a tackle.

Special lashings.

There are also certain lashings used for special purposes—as, for example, the lashing used to connect barrels into a pier for a floating bridge. These are dealt with when those special purposes are considered.

TABLE F.

TIMBER IN COMPRESSION.

Kind of Timber.	Ultimate Resistance, Pounds per Square Inch.			Average Working Stresses. Pounds per Square Inch.		
	With Grain. End Bearing.	With Grain. Columns under 15 Diameters	Across Grain.	With Grain. End Bearing.	With Grain. Columns under 15 Diameters.	Across Grain.
White oak	7,000	4,500	2,000	1,400	900	500
,, pine	5,500	3,500	800	1,100	700	200
Southern, long-leaf or Georgia yellow pine	8,000	5,000	1,400	1,600	1,000	350
Douglas (Oregon) and yellow fir	8,000	6,000	1,200	1,600	1,200	300
Northern or short-leaf yellow pine	6,000	4,000	1,000	1,200	800	250
Red pine	6,000	4,000	800	1,200	800	200
Norway pine	6,000	4,000	800	1,200	800	200
Canadian (Ottawa) white pine	...	5,000	...	...	1,000	...
Canadian (Ontario) red pine	...	5,000	...	...	1,000	...
Spruce and Eastern fir	6,000	4,000	700	1,200	800	200
Hemlock	...	4,000	600	...	800	150
Cypress	6,000	4,000	700	1,200	800	200
Cedar	6,000	4,000	700	1,200	800	200
Chestnut	...	5,000	900	...	1,000	250
California redwood ...	...	4,000	800	...	800	200
,, spruce ...	...	4,000	...	...	800	...

TIMBER IN TENSION.

Kind of Timber.	Ultimate Resistance. Pounds per Square Inch.		Working Stresses, Pounds per Square Inch.	
	With Grain.	Across Grain.	With Grain.	Across Grain.
White oak	10,000	2,000	1,000	200
,, pine	7,000	500	700	50
Southern, long-leaf or Georgia yellow pine ...	12,000	600	1,200	60
Douglas (Oregon) and yellow fir	12,000	...	1,200	...
Washington fir or pine (red fir)	10,000	...	1,000	...
Northern or short-leaf yellow pine	9,000	500	900	50
Red pine	9,000	500	900	50
Norway pine	8,000	...	800	...
Canadian (Ottawa) white pine	10,000	...	1,000	...
,, (Ontario) red pine	10,000	...	1,000	...
Spruce and Eastern fir ...	8,000	500	800	50
Hemlock	6,000	...	600	...
Cypress	6,000	...	600	...
Cedar	8,000	...	800	...
Chestnut	9,000	...	900	...
California redwood	7,000	...	700	...

TABLE G.
MARKET SIZES OF TIMBER.

Name of timber.	Botanical name.	Round sections.	Square sections.	Scantlings.
Baltic fir or redwood ... Spruce, white fir or Baltic whitewood	Pinus Sylvestris ... Picae Excelsa ...	Hand masts, from 24″ cir. near butt and 36′ long, to 72′ cir. and 74′ long Below these dimensions known as spars or poles	12″ or rather more in side, up to 35′ or 40′ long	Battens and deals, 4″ to 10″ wide, 2″ to 4″ thick, up to 22′ long. Planks 11″ wide or over, of various thicknesses and 12′ and upwards in length
White pine or yellow pine ...	Pinus Strobus	...	16″ in side, up to 40′ long. up to 24″ in side in shorter lengths	Deals and battens, from 7″ wide up to considerable widths
Longleaf pine or pitch pine...	Pinus Palustris	...	11″ or 12″ in side, 35′ long, up to 50′ long at a high price	
Douglas fir or Oregon pine ...	Pseudo-tsuga Douglasii ...	...	14″ to 18″ in side, 60′ long, up to 20″ in side in shorter lengths	
Kauri pine	Agathis Australia	...	...	24″ wide or over, up to 18′ long
(1) English oak and (2) Baltic oak	(1) Quercus Pendunculata (2) Quercus Sessiliflora	...	10″ to 16″ side, 12′ to 18′ long, roughly squared	15″ wide, 2″ to 8″ thick
Teak	Tectona Grandis	...	9″ to 24″ in side, 12′ to 30′ long	9″ to 24″ wide, 2″ to 8″ thick, 6′ to 24′ long
Greenheart	Nectandra Rodiei	...	12″ to 16″ in side at centre up to 45′ to 65′ long 12″ in side, sawn straight, 35′ long	
Blue gum	Eucalyptus Globulus ...	...	18″ to 20″ in side, up to 60′ long or over, square hewn	
Bamboo	Bambusa Vulgaris	Up to 8″ diam. up to 60′ long		

TABLE II.

Strength of Iron and Steel, etc.

Material.	Stress in tons per square inch.						Coefficients of elasticity. lbs., sq. inch.	Weight. lbs. per cubic ft.
	Tenacity.		Compression.		Shear.			
	Ultimate.	Working.	Ultimate.	Working.	Ultimate.	Working.		
Cast-iron	7–10	1·5	40–50	5	9-11	1·25	6,000–9,000	450
Malleable cast-iron	16–22	...	21	...	...	...	...	...
Wrought-iron bars	20–24	5·5	12-16	5·5	15–18	3·5	12,000-13,000	
,, plates, with grain... ...	21	5·5	...	...	16	...	12,000-13,000	480
,, ,, across grain ...	19	5·5	...	...	14	...	12,000-13,0 0	
Mild or structural steel	28–32	6	14–17	6	21-24	3·75	13,000-14,000	
,, ,, ,, for rivets ...	26–29	...	...	...	...	...	13,000-14,000	490
Medium steel, as rails	30–40	7·5	...	7·5	...	5·5	13,000-14,000	
Hard steel	35–70	9·5	....	9·5	45	9	13,300-14,000	
Steel wire	70–90	...	...	...	...	...	13,000-14,000	....
Copper, cast	6–10	...	20	...	...	...	6,000-7,000	
,, hard drawn	20	...	...	...	...	...	6,000-7.000	550
,, annealed	13	...	...	...	...	...	6,000-7,000	

N.B.—The working stresses are for steady loads in one direction only.

(*a*) Where the load is repeated so as to alternate many times between no stress and stress of one kind, use two-thirds of these values.

(*b*) Where the stress alternates many times between tension and compression of the same amount, use one-third of these values.

Table J.—*Sample Minimum Breaking Loads from Government Specification.*

Nature of cordage.		Breaking load. Cwts. per (circ. in inches)².
Hemp, bolt, 3-strand, tarred ...	...5-inch	7·60
,, ,, ,, ...	...2 ,,	7·50
Hemp, hawser, 3-strand, tarred	...4 ,,	6·25
,, ,, ,,	...3 ,,	6·66
,, ,, ,,	...2 ,,	6·75
,, ,, ,,	...1 ,,	8·00
,, ,, white	...9 ,,	8·15
,, ,, ,,	...4 ,,	9·06
,, ,, ,,	...1 ,,	12·00
Manila, ,, tarred	...5 ,,	7·36
,, ,, ,,	...2½ ,,	7·44
,, ,, ,,	...1 ,,	9·00
,, ,, white	...5 ,,	8·10
,, ,, ,,	...2½ ,,	9·60
,, ,, ,,	...1 ,,	10·50
Coir, ,, ,,	...9 ,,	1·58
,, ,, ,,	...5 ,,	1·60
,, ,, ,,	...2½ ,,	1·54

Table K.—*Experimental Breaking Loads of Commercial Cordage.*

Nature of cordage.	Breaking loads. Cwts. per (circ. in inches)².	
Hemp, tarred	(average)	4·94
,, ...	(maximum)	8·31
,, ...	(minimum)	3·19
Hemp, white	(average)	6·76
,, ...	(maximum)	8·52
,, ...	(minimum)	5·54
Manila	(average)	7·64
,, ...	(maximum)	10·56
,, ...	(minimum)	4·25
Cotton	(average)	4·64
,, ...	(maximum)	5·71
,, ...	(minimum)	3·68

Table L.—*Experimental Breaking Stresses of Commercial Steel Wire Ropes.*

Nature of rope.	Breaking stress. Tons per (circ. in inches)².	
Wire core, ungalvanized	(average)	3·08*
,, ,, ...	(minimum)	2·55
,, galvanized	(average)	2·62*

* These figures are based on but few experiments; in general they would be higher.

Table L—*continued.*

Nature of rope.	Breaking stress. Tons per (circ. in inches)².	
Hemp main core, ungalvanized	(average)	3·20
" " "	(maximum)	4·51
" " "	(minimum)	2·43
" " galvanized	(average)	2·70
" " "	(minimum)	1·92
" " and strand cores, ungalvanized	(average)	2·76
" " " " galvanized ...	(average)	2·25
" " " " " ...	(maximum)	3·52
" " " " " ...	(minimum)	1·77

Table M.—*Experimental Values of the Breaking Stresses of Iron and Steel Wire.*

Nature of wire.	Breaking stress. Tons per square inch.	
Iron wire...	(average)	32
"	(maximum)	44
"	(minimum)	26
Steel wire	(average)	97
"	(maximum)	142
"	(minimum)	46

TABLE N.

NAILS.

Vocabulary description.	Length.	Number to one pound.
Nails, wire iron, grooved	6-inch	15
" "	5 "	20
" "	4 "	35
" "	3 "	67
" "	$2\frac{1}{2}$ "	72
" "	2 "	165
" "	$1\frac{1}{2}$ "	243
" "	$1\frac{1}{4}$ "	367
" "	1 "	894
Rosehead, No. 128	$4\frac{1}{4}$ "	26
" " 126	$3\frac{1}{4}$ "	40
" " 124	$2\frac{3}{4}$ "	59
Cut, clasp	$1\frac{1}{2}$ "	248
Countersunk, No. 109	$3\frac{1}{4}$ "	21
" " 108	$2\frac{1}{2}$ "	29
" " 106	2 "	45
" " 104	$1\frac{1}{2}$ "	104

Spikes.

Vocabulary description.	Length.	Weight each.
Nails, iron spike, No. 187	10-inch	—
,, ,, 186	9 ,,	¾ lb.
,, ,, 185	8¼ ,,	9½ ozs.
,, ,, 184	7 ,,	8⅓ ,,
,, ,, 183	6¼ ,,	7 ,,
,, ,, 182	5¼ ,,	3¼ ,,

Coach Screws.

Vocabulary description.	Length.	Weight each.
Coach screws	5-inch	9 ozs.
,, ...	6 ,,	10 ,,
,, ...	9 ,,	13 ,,
Dogs, railway and sawyers, straight	15 ,,	3 lbs.
,, ,, ,,	12 ,,	2 ,,

TABLE O.

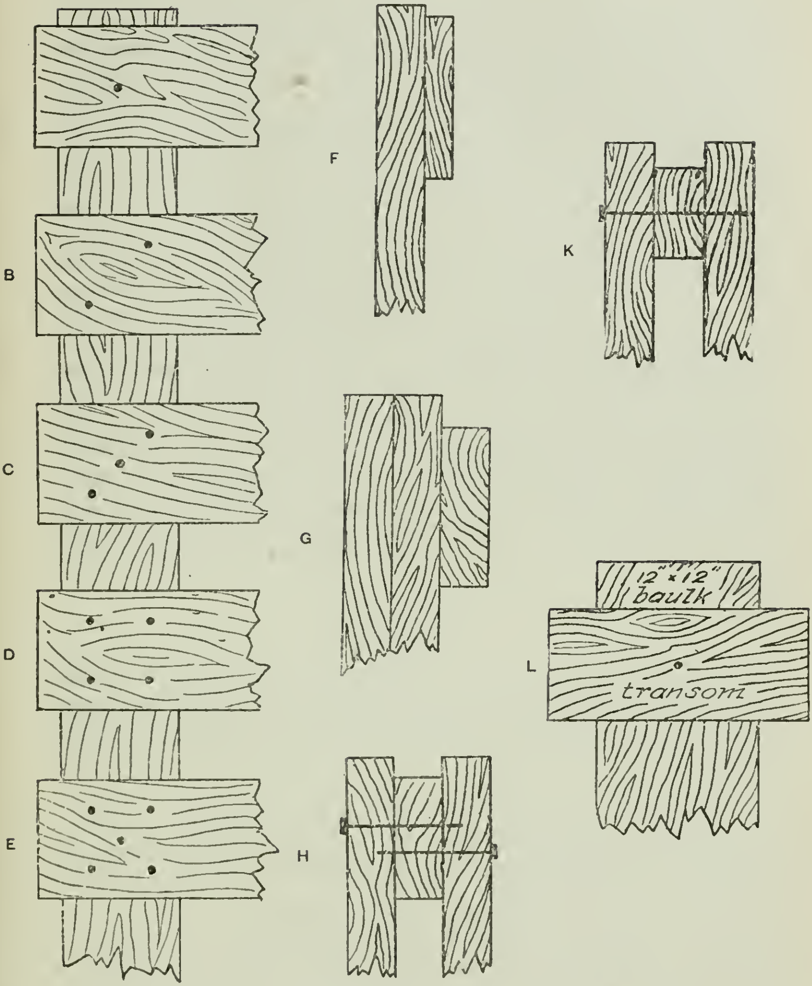
This table gives the average results of tests made at Chatham to ascertain the holding power of nails. Except where stated the result is the average of three tests. The timber was sound seasoned deal free from large knots. Each end of the transom was similarly nailed, the nails being driven at right angles to the face of the timber. The nails failed in all cases by drawing their pointed ends. The spikes were driven with their chisel point across the grain of the timber of less thickness, that is with the grain of the baulk. They failed in every case by drawing out of the baulk.

—	No. of nails in each end of transom.	Arrangement of nails, *see* details.	Arrangement of timber, *see* details.	Logs made of—	Transom composed of—	First signs of failure at—	Collapse of transom at—	Remarks.
						Cwts.	Cwts.	
3″ grooved wire nails	1	A	F	2″ deal	1″ deal	3	7·6	
	2	B				9	15	
	3	C				13	22·6	
	4	D				16·3	36·3	
	5	E				20·6	37·6	

TABLE O—*continued.*

—	No. of nails in each end of transom.	Arrangement of nails, *see* details.	Arrangement of timber, *see* details.	Logs made of—	Transom composed of—	First signs of failure at—	Collapse of transom at—	Remarks.
						Cwts.	Cwts.	
4″ grooved wire nails	1	A	F	2″ deal	1″ deal	4·3	11	Ends not clenched.
	2	B				10·3	27·6	
	3	C				15·6	31·3	
	4	D				18·6	51·3	
	5	E				20·3	59·3	
4″ grooved wire nails	1	A	F	2″ deal	1½″ deal	6	12	Ends not clenched.
	2	B				10	24·6	
	3	C				15	34·6	
	4	D				18	46	
	5	E				22·6	56·6	
4″ grooved wire nails	1	A	F	2″ deal	2″ deal	8·3	8·8	
	2	B				15	20·1	
	3	C				24·3	30·6	
	4	D				29·3	42	
	5	E				40·6	54·6	
5″ grooved wire nails	1	A	G	2—2″ deal	2″ deal	11·6	13·6	
	2	B				19·6	24·6	
	3	C				27·6	31·8	
	4	D				44·6	55·3	
	5	E				57·3	68	
6″ grooved wire nails	1	A	G	2—2″ deal	2″ deal	15·5	18	
	2	B				29·3	37	
	3	C				47·6	58	
	4	D				53	65·5	
	5	E				65·6	90·3	
4″ nails, clasp No. 86	1	A	F	2″ deal	2″ deal	8·3	8·6	
	2	B				15	20·6	
	3	C				18	26	
	4	D				25	36	
	5	E				33	48·3	
5″ grooved wire nails	1*	A*	H	2—2″ deal	2″ deal	23·6	28	*On either side.
	2*	B*				63·5†	67·5†	†Average of two tests only; in third case timber failed at 38 cwts.
	3*	C*				71·6	85·6	
6″ grooved wire nails	1	A	K	2—2″ deal	2″ deal	22	32·6	
6″ grooved wire nails	1	A	F	2″ deal	2″ deal	11	15	Projecting 2″ clenched down.
Nails, spike, 6″	...	...	L	12″ × 12″ fir baulk	9″ × 3″ deal	11	14·5	
,, ,, 7″	...	...				17·3	25·3	
,, ,, 8″	...	...				25	36·6	
,, ,, 9″	...	...				20·6	40·6	
,, ,, 6″	...	...			9″ × 2″ plank	12·3	21·6	

Details.



Graphical Determination of Section Modulus.

Suppose the scale to be employed is 1/n, draw the cross-section, the modulus of which is to be determined, to this scale on a piece of squared paper. Draw two lines parallel to the horizontal dimension of the beam when in use, touching the extreme limits of the section, and let these lines be parallel to the lines on the squared paper. Draw a line parallel to and half- ay between these two lines, and suppose the distance between this central line and either of the uter ones to be D. Choose some point in the central line as a pole, and proceed to find a "modified section" on either side of the central line, defined by the locus of the intersection of a line drawn from the pole to the foot of the perpendicular on the outer line from a point on the outline of the original section, with a line parallel to this outer line through the same point on the original section. From this first modified section obtain a second modified section in precisely the same way. (Pl. XXX.) Measure the areas of the original, the first and the second modified sections, above and below the central line respectively, by a planimeter or by counting the squares. Suppose these areas to be: Original area, a and b; first modified area, a_1 and b_1; and second modified area, a_2 and b_2 above and below the central line respectively. Then the perpendicular distance of the centre of gravity from the central line is—

$$n \frac{a_1 \sim b_1}{a + b} \mathrm{D}$$

the centre of gravity being on that side of the central line where the first modified area is greater, and the moment of inertia about a line through the centre of gravity parallel to the lines drawn is—

$$n^4 \left\{ a_2 + b_2 - \frac{(a_1 \sim b_1)^2}{a + b} \right\} \mathrm{D}^2$$

The section modulus of the cross-section will therefore be given by the expression—

$$\mathrm{Z} = n^3 \frac{\left\{ a_2 + b_2 - \frac{(a_1 \sim b_1)^2}{a + b} \right\}}{1 + \frac{a_1 \sim b_1}{a + b}} \mathrm{D}$$

Regulations for Testing Spars, Ropes and Cordage.

All spars used for instructional bridging should be tested annually. The test load should be the safe working load plus 25 per cent. This should be applied centrally over the longest

span which the spar can cover. Pairs of bollards should be fixed in the ground to give clear spans of 10, 15, 20, 30, 35, 40 and 50 feet, and the load should be applied by means of a wire rope extending from a winch to the centre of the spar. In order to measure the load, a "machine, testing and weighing," should be used. One of these is held on charge by the Army Ordnance Department in each command for issue on loan when required. The wire rope should be attached to one end of the machine, while to the other a sling should be fixed which should be fastened round the centre of the spar under test. The winch must be fixed to an anchorage amply capable of sustaining the load to be applied to any spar.

The table given below contains the central test load for fir spars, the modulus of rupture being taken at 6,000 lbs. per square inch and the factor of safety at 3.

The test will consist in noting the deflection of the spar under the load, seeing that it is not excessive and that there is no permanent deflection in the spar when the stress is removed. The maximum deflection generally permissible should not exceed about one-eightieth of the span. Spars which show an excessive deflection or a permanent set should be cast. In the case of light spars which are not intended to carry a load, *e.g.*, handrails, a greater deflection than that mentioned may be allowed, provided there is no permanent set.

Central Test Loads for Spars.

Circumference of spar in inches at its centre.	Loads in cwt. Span in feet.				Circumference of spar in inches at its centre.	Loads in cwt. Span in feet.						
	10	15	20	30		10	15	20	30	35	40	50
11	3	2	1½	1¼	31	70	46	35	23	20	17½	14
12	4	2½	2	1¼	32	78	52	39	26	22	19	15½
13	5	3½	2½	1½	33	85	56½	42½	29	24	21	17
14	6	4	3	2	34	91	62½	46	31	26	23	18½
15	8	5	4	2½	35	100	68	50	34	29	25	20
16	10	6½	5	3	36	110	74	55	37	31	27	22
17	11	8	5½	4	37	119	80	60	40	34	29	24
18	14	9	7	4½	38	129	86	64	42	37	32	26
19	16	11	8	5½	39	...	94	69	46	41	34	28
20	19	13	9½	6½	40	...	100	75	50	43	37	30
21	21	15	10	7½	41	...	107	80	54	46	40	32
22	25	17	12½	8½	42	...	116	87	58	50	43	35
23	29	19½	14½	10	43	...	125	93	62	53	46	37
24	33	22	16½	11	44	...	...	100	67	57	50	40
25	38	24	19	12	45	...	...	107	72	61	53	43
26	41	28	21	14	46	...	...	114	77	65	57	46
27	46	30½	23	15	47	...	...	122	82	70	60	49
28	52	34	26	17	48	...	...	130	87	75	64	52
29	58	38	29	19	49	...	...	...	92	79	68	55
30	64	42	32	21	50	...	...	...	99	84	73	59

Ropes and Cordage.

The test load for ropes and cordage will be the safe working load plus 25 per cent. This may be applied in a manner similar to the test load for spars, use being made of the "machine, testing and weighing," for measuring the load. The rope or cordage should be laid out at full length along the ground, one end being connected to the barrel of the winch and the other passed through the sheave of a single block and made fast to itself by two half hitches. The block is hooked into the testing machine. The object of the block, which contains a swivel, is to allow the rope to unlay itself.

For steel wire rope the test loads are given below. These are calculated on the assumption that the breaking strain equals $7/4\ C^2$ in tons and that a factor of safety of 3 is used. Should the rope be known to be of a superior quality to this, the test loads may be altered accordingly.

Test Loads for Steel Wire Rope.

Circumference in inches.	Loads in cwts.
1	14½
1½	33
2	58
2½	90
3	130

It will not be easy to apply test loads to 3-inch ropes and upwards on account of their magnitude. If it is not possible the ropes must be carefully examined throughout their length for signs of weakness. The circumference of worn ropes should be accurately measured and the working load reduced accordingly.

For hemp cordage the test loads are given in the following table. In this the loads are calculated from the two formulae: C^2 cwt. and $2\ C^2$ cwts. The actual load to be applied in each case must be determined between these limits according to the condition of the cordage.

Test Loads for Hemp Cordage.

Circumference of cordage in inches.	Loads will vary according to condition of cordage.	
	From—	To—
	cwts.	cwts.
1	1¼	2½
1½	2¾	5½
2	5	10
2½	8	16
3	11¼	22½
3½	15½	31
4	20	40

SECTION V.—ACCESSORIES REQUIRED FOR BRIDGING OPERATIONS.

1. Blocks are used for the purpose of changing the direction of ropes and of gaining power at the expense of time. They are identified by their material, number of sheaves and length of shell. Blocks.

The main parts of a block are the strap, pin, shackle or hook, shell and sheave.

The framework of the block consists of two parts—the strap which holds the pin on which the sheave revolves and to which a shackle or hook is attached for carrying the weight, and the shell whose principal use is to prevent the rope slipping off the sheave. The shell of an iron block is made in one piece with the strap.

The sheave is made of metal—iron in the case of iron blocks, and brass or gunmetal for wooden blocks or blocks of a superior type. The diameter of the sheave is dependent on the size of rope to be used; if the sheave is too small the strength of the rope, especially if wire rope is used, is seriously diminished, and a proportion of the power is lost. On the other hand, the smaller the sheave the lighter the block. A rough rule holds with wooden blocks that the length of the shell is three times the circumference of the largest rope it will take. Iron blocks have a shell of a less proportionate length. There is a tendency in practice to use a wire rope of the maximum size that will work in the sheave. But this is a mistake, as it brings a very unfair stress on the rope. For wire ropes, a good rule is to use a sheave whose diameter is six times the circumference of the rope. The sheave revolves on the pin which is fixed in the framework of the block.

One, two or three sheaves may be fitted in one frame, and the blocks are called single, double and treble. Single blocks are sometimes made with a cut in one side of the shell, so that a rope can be admitted without passing its end through. Such blocks are known as snatch blocks.

A becket or eye is fitted to the other end of the block from the hook, to which the standing end of the fall is attached.

2. Ordinary tackles are composed of one or more blocks, rove with a rope or fall. Tackles.

The fall is the rope employed to connect the blocks.

Reeving is the operation of passing the fall round the sheaves of the blocks.

The *standing end* is the end of the fall made fast to one of the blocks.

The *running end* is the loose end of the fall, to which the power is applied.

The parts of the rope between the blocks are known as *returns*.

To *overhaul* is to separate the blocks.

To round in is to bring them closer together. When the blocks are as close as they will go, they are said to be *chock a block*.

Ropes which are to be used for reeving tackles should be well stretched, or the blocks will have a tendency to twist. This can be done conveniently by making one end fast to a swivel and applying power to the other; the rope can then unlay as it is tautened.

Reeving. A tackle is rove by two men, standing back to back, 6 feet apart. The blocks should be on their sides between the men's feet, hooks to their front, and the coil of rope to the right of that block at which there are to be the greater number of returns. Beginning with the lowest sheave of this block, the end of the fall which is to be the standing part is passed successively through the sheaves of both blocks from right to left, and then made fast to the proper block. The standing end is usually secured to the becket by two half hitches. The half hitches should be as close up as possible, and very little spare end left for seizing, so that the blocks may not become chock unnecessarily soon.

With tackles for a heavy lift, it is better to reeve the fall so that the running end comes off the centre sheave. To do this, pass what is to be the standing end of the fall through the centre sheave of one block, then through the centre sheave of the other, next through either the lower or upper sheaves of each block consecutively; one return will cross the centre one, but as they will be moving in the same direction the friction will be trifling.

A convenient way of overhauling a heavy tackle is to secure the block from which the running end comes off to some holdfast and to place a handspike in the hook of the other block, with a drag-rope made fast to it. To overhaul the tackle, the handspike and drag-rope are manned, while one or two men overhaul the returns from the standing block. Rounding in is the converse; the men on the handspike and drag-rope hang back, while a few men heave on the running end. The handspike is to keep the tackle out of the dirt, which would clog the sheaves.

With long, heavy tackles, it is better to reeve the blocks the working distance apart, to save overhauling after reeving.

Leading blocks. In order to allow the motive power to be applied favourably on the fall, a leading block is often required. This is made fast to a holdfast, close to the ground, properly placed so as to give a good lead to the fall which runs through it. A snatch block is frequently used for this purpose. It is often necessary to lash the fixed block of the tackle to a spar. The method is as follows:—The back of the hook is laid against the spar, a clove hitch made on the spar above the hook and several turns taken round the hook and spar, finishing off with two half hitches below the hook. The number of turns necessary depends on the stress coming on the block and on the rope used for the

lashing. With cordage the stress allowable in each return of the lashing is four-fifths of the safe stress in the rope, this fraction being used to allow for unequal distribution. With wire rope the allowable fraction is three-fifths, as the lashing is more difficult to adjust equally. The total stress on the lashing is the stress on the block multiplied by the secant of half the angle included by the returns of the lashing. In practice it is accurate enough to multiply the stress on the block by $1\frac{1}{2}$ to give the total stress on the lashing.

The fixed block can also be hooked into a sling. Slings should be so adjusted that the splice is not round any edges nor over the hook. They should not be left to adjust themselves, but should be so arranged that the stress may be equally divided between all the returns. For heavy lifts chain slings should be used.

The weight to be lifted will generally have to be connected to the movable block by means of a sling, and the same precautions must be adopted in adjusting it. Heavy weights with edges, projections or corners should be carefully padded with old sacking or suitable pieces of wood to prevent damage to the sling. If the sling is arranged in two portions its return should cross over the hook. (Pl. XXXIII, Fig. 1.) The stress in the sling is found in the same manner as for the lashing of a block. The nearer the point of suspension is to the weight, the greater the stress on the sling.

Anti-twisters.

In using tackles care must be taken to prevent the running end of the fall from pressing against the shell or from twisting the blocks. If the tackle twist a complete turn, the power required is increased over 40 per cent. To prevent twisting, a handspike can be placed between the returns close to the block and kept in its place by two lashings at its ends, or a crowbar can be lashed at the top of the block in the required position. With light runner tackles it is usually sufficient to lash the handle of a maul to the block. The lashing should be passed round the head and up the handle to prevent the maul working out. Reeving long tackles, so that the running end comes off the centre sheave, will do a great deal to prevent twisting. A properly stretched fall and the use of anti-twisters on the blocks wherever practicable, or other preventive measures, will amply repay the time and trouble expended on them.

Actual advantage gained by tackles.

3. Theoretically, with frictionless blocks, the power necessary in any system of tackle of two blocks to raise a weight or overcome a force, is that weight or force divided by the number of returns of the fall at the movable block, including the standing end of the fall if that is made fast to that block. In practice, the unavoidable amount of friction very seriously diminishes the theoretical mechanical advantage. The loss of power involved in this way may be considered under three heads.

Firstly, the friction of the parts of the rope against each other

or against the shell of the block. This can be diminished by keeping the returns parallel and preventing the blocks twisting. The loss from this cause may vary from nothing up to any amount, as it is quite possible if the tackle is twisted sufficiently to stop all movement.

Secondly, the friction between the sheave and the pin. This cause is present in all blocks and cannot be entirely eliminated. A great deal can be done by taking care of the tackle, and seeing that it is well lubricated.

Thirdly, the power used in bending the fall round the sheave and straightening it again. This cause is always present. It is greater with wire rope than with cordage, and with tarred cordage than with white. To allow for the effect of friction, a certain fraction of the theoretical power is added for each sheave in the tackle, including any leading blocks, to obtain the power that will actually be required:—

$$P = \frac{W}{G}(1 + fn)$$

where P is the power actually required to lift the weight or overcome the force, W the weight to be lifted, G the theoretical advantage or number of returns at the movable block, f a coefficient of friction, and n the total number of sheaves.

The value to be given to the coefficient f depends on the condition of the tackle. With tackle in excellent condition it may vary from $\frac{1}{8}$ to $\frac{1}{10}$; for average tackles with falls of tarred rope it may be taken as $\frac{1}{6}$, and for tackles in bad condition may be as high as $\frac{1}{5}$ or more.

Types of tackles.

Broadly speaking tackles can be used vertically or horizontally, and can be thus divided into lifting tackles and runner tackles. In either case it is generally necessary to lead the running end of the fall off in a horizontal direction, in order that the power employed may work in the most advantageous manner. It will thus be seen that in general, lifting tackles have the running end of the fall coming from the fixed block and also passing through a leading block, and runner tackles have the fall coming from the movable block, with no leading block.

Following the above division, the more ordinary tackles may be grouped as follows:—

1. Lifting or main tackles.
   - (1) Single fixed block. (Pl. XXXI, Fig. A.)
   - (2) Two single blocks, known as a single whip. (Fig. B.)
   - (3) Whip upon whip. (Fig. C.)
   - (4) Single and double block, known as a luff tackle. (Fig. D.)
   - (5) Two double blocks, known as a gun tackle. (Fig. E.)
   - (6) Double and treble blocks, known as a light gyn tackle. (Fig. F.)
   - (7) Two treble blocks, known as a heavy gyn tackle. (Fig. G.)

II. Runner tackles.

(1) Single movable block, known as a single whip. (Pl. XXXII, Fig. A.)
(2) Whip upon whip. (Fig. B.)
(3) Two single blocks. (Fig. C.)
(4) Single and double block, known as a luff tackle. (Fig. D.)
(5) Two double blocks. (Fig. E.)
(6) Double and treble block. (Fig. F.)
(7) Two treble blocks, known as a heavy gyn tackle reversed. (Fig. G.)

The power required for these several tackles, to lift a given weight or overcome a given force, can be seen by inspection on Pls. XXXI and XXXII.

4. It has been found by experiment that squads of men, up to 60 in number, can exert about half their weight on a horizontal fall. Two or three men, pulling upwards or downwards, can each pull more than this; but more cannot work together. With men of average weight, their pull can be taken as 80 lbs., or $\frac{3}{4}$ cwt., according to the unit employed. A smaller fall than 3 inches is difficult to haul on, and wire rope is harder to haul on than cordage. Motive power.

When greater motive power is required than can be obtained from men alone, one of the machines to be described presently must be used.

The amount of stress in the beam or anchorage to which the fixed block is secured can be taken as the power required on the tackle multiplied by the number of returns at the fixed block. Stress at fixed block.

5. Steadying ropes should be securely attached to the weight and used to regulate its position gently, especially when lifting out of the perpendicular and also to prevent surging or swinging. Practical points.

When a weight has to be left suspended by a tackle if working at all near its safe limit, the fall should be eased off a little after raising, to distribute the stress in the returns.

The weight may be left suspended by fastening any two opposite returns of a tackle together, so that the blocks may retain their relative position, although the running end be let go. This is known as racking a tackle, and a rack-lashing may be used to stopper the returns of a tackle in this way.

For other practical points to be attended to in the arrangement and use of tackles, *see* "Garrison Artillery Training," Vol. III, 1911, Chapter VII.

6. Crane chain may also be used as a fall, but should be thoroughly soaked in oil. If it is rusty the excess of power required over the theoretical amount may be as much as 30 per cent. for each sheave. If well lubricated it should not be more than that required for cordage. Use of chain falls.

7. A differential tackle consists of two unequal pulleys, keyed on to the same shaft and revolving together. An endless chain Differential tackles.

is passed round both pulleys, with two bights hanging down. One of these bights carries the weight hooked to a small pulley travelling on the chain, while the motive power is applied either to the other bight, or in the case of the larger sizes to a separate chain passing round another pulley geared to the main pulleys. The theoretical gain of these tackles is considerable, that of the $\frac{1}{4}$-ton tackle being about 16 and of the $1\frac{1}{2}$-ton tackle about 34; while that of the larger sizes with the extra pulley is even greater. To allow for friction, the theoretical power required should be increased by about one-third in the case of the simple form and by about one-half in the case of the form with the extra pulley.

Field capstan. 8. The service pattern of field capstan weighs about 4 cwts., has a vertical barrel and is worked by two capstan bars. The frame of the capstan is secured to pickets or some other holdfast, which must be capable of withstanding the stress exerted by the capstan.

The running end of the fall is passed at least four times round the barrel, the end coming off above the turns, the other end being attached to the weight to be moved. The running end must come to the capstan at right angles to the axis of the capstan, a leading block being employed if necessary to make it do so. The running end is held by two or more men. If difficulty is found in holding on to the running end owing to the barrel being slippery, another turn should be taken round it, but on no account should sand or grit be placed on the rope to make it bite. Before taking the weight the turns must be shifted to the top of the barrel and the slack rove in by hand. Before lowering the weight, the turns should be shifted to the bottom of the barrel. The barrel is conical to facilitate the turns slipping up when hoisting; it is therefore difficult to keep them down when lowering and they are consequently inclined to jam.

The number of men on the bars varies with the power required, but two, or at the most three, are all that can work at the end of each bar. By "swifting" or joining the ends of the bars with rope 16 men altogether can work, eight on the four ropes.

The theoretical gain of the capstan is about 13, but in practice the actual pull obtained is approximately as given below :—

Number of Men on Capstan.	Cwts.	Number of Men on Capstan.	Cwts.
1	12	9	54
2	20	10	58
3	25	11	62
4	30	12	66
5	35	13	70
6	40	14	74
7	45	15	77
8	50	16	80

In working up to the maximum stress there is a risk of splitting the capstan head.

A substitute for a capstan may be formed out of a stout wheel, laid upon its face on the ground with an axle put into it, fitted with a round piece of timber as the barrel of a capstan, and bars to work it lashed across the head. (Pl. XXXIII, Fig. 2.)

9. Winches are mounted on vertical wooden frames, which must be secured to the ground. They have a horizontal barrel, round which the turns of the fall are taken in the same way as in the capstan. The power is applied to a handle at each end, and further mechanical advantage is gained by the power being transmitted through toothed wheels. The system of gearing is generally such that there is a slow and a quick purchase, the weight to be lifted determining which is to be used. Winches.

The theoretical advantage depends on the gearing and can be worked out in the usual manner for any particular winch. Unless kept well lubricated, an excess of power through friction losses of at least 25 per cent. will be required.

When lowering light weights the brake may be employed; but it must be done slowly, the fall kept in hand in rear, and the handles should be removed. When lowering heavy weights the brake may be used to assist, but the handles must be manned and the weight kept well under control.

There are several service patterns of gyns, which combine some form of windlass or winch with the frame of the gyn. Paras. 16–21 describe how to extemporize them, and other means of lifting weights in the field. Service gyns.

10. There are three varieties of jacks used in the service :— Jacks.

(1) The general service jack, which consists of lever arms, and will lift up to ½ ton.
(2) Screw jacks, which have a vertical screw worked by a ratchet and lever. They will lift up to 5 tons, and also generally have a traversing motion.
(3) Hydraulic jacks of different sizes, lifting from 7½ to 30 tons. There are several different patterns, but they all work on the same principle, that the pressure per square inch on a small area of a plunger worked by a hand lever will be same as the pressure per square inch on a large area, which consequently raises the weight.

Jacks must be treated with care and kept free from any grit or dirt.

For lifting weights, jacks must be used vertically and if possible in pairs. It is most important to follow up the weight with packing, which must be carefully arranged.

Jacks may also be used to exert a thrust in other directions than the vertical.

11. A lever cart or devil cart is convenient for lifting timber. Lever carts.

It consists of a pair of wheels, an axle and a pole secured to the centre of the axle, with its butt projecting from 1 to 2 inches to the rear and furnished with a hook. (Pl. XXXIII, Figs. 3 and 4.) The wheels are run over the centre of gravity of the log, and a rope or chain sling passed under it and hooked to the butt of the pole, which is lowered by raising the tip; the latter is then pulled down, which raises the log, to which it is then lashed. Large wheels are convenient, as large logs can then be dealt with.

A cart of this nature can be improvized out of any strong pair of wheels with a good axle.

Rollers.

12. Rollers are solid cylinders, generally made of some hard wood, and vary in diameter and width according to the purpose for which they are required. They give no mechanical advantage, but substitute resistance to rolling in place of friction. The power required to move a weight on a level planked roadway on hard wood rollers varies from one-sixteenth of the weight to start it to one-twenty-fifth to keep it moving. On soft ground the power required is largely increased, and lashings or projections on the weight offer considerable resistance to movement. If the weight is also being moved up an incline, the component of the weight must be added to the power required. The direction of a weight moving on rollers can be altered by adjusting or "cutting" the rollers. This adjustment of rollers necessitates an increase in the power.

Further information on the subject of rollers can be obtained from "Garrison Artillery Training, Vol. III," Chap. XVI.

Holdfasts and anchorages.

13. In many forms of bridging, and in many of the operations connected with the raising of weights and so forth, fixed points are necessary, to which cables may be attached. Such fixed points consist of holdfasts, anchorages and anchors. In securing a cable to a holdfast, from which it may be necessary to ease off, at least one complete turn must be taken before making fast, otherwise when the stress is on it is difficult to cast off.

Natural holdfasts.

Suitable holdfasts may sometimes be found in the shape of trees. They must be examined to see if they are sound or not, and their strength depends not only on their size, but also on the nature of their growth, as some trees strike their roots further into the ground than others.

Ready-made holdfasts may sometimes also be found, as, for example, ring-bolts; but they should not be trusted until carefully examined.

Holdfasts can be made by placing baulks across openings in masonry. In such cases the stress should be distributed over a large surface by placing planks for the baulk to bear against. Slings round piers of arches may be used, but all corners should be protected by wood, or the rope itself parcelled to prevent chafing or cutting.

Picket holdfasts.

For comparatively small pulls in ordinary soil, holdfasts made of pickets or groups of pickets may be used. The pickets may

be improvised, but the service pattern, known as "park pickets," are more convenient. The latter are made of ash, shod with an iron point, hooped with iron at the other end to prevent splitting, and frequently provided with a ring at the top. The usual lengths are 2 feet 6 inches and 5 feet.

These pickets may be used singly for a small pull, and are generally driven at right angles to the line of the pull, but they are more frequently used backing each other up. Several combinations are possible: 1—1, 1—1—1, 2—1, 3—2—1. (Pl. XXXIII, Fig. 5.) In all such cases the pickets should be parallel and at right angles to the line of the cable. The lashings connecting the several pickets should be at right angles to the pickets, and should come from the head of the picket in front to the ground level of the backing-up picket. These lashings should be racked up tight with a "Spanish windlass." The backing up may be done by a horizontal log buried in the ground. (Pl. XXXIII, Fig. 6.)

In driving pickets of different sizes the strongest should be nearest the weight. It has been found that a 3-inch park picket of ash 5 feet long, driven 3 feet into loam at a slope of 2 : 1 began to yield with a pull of 14 cwts. applied at the surface of the ground at a slope of 1 : 2, and when the pull was increased to 1 ton the picket broke at the surface of the ground; this was a failure of the picket. The same pickets, similarly driven 2 feet and 1 foot, drew at a pull of 11 cwts. and $9\frac{1}{2}$ cwts. respectively; this was a failure of the ground. 5-foot pickets, driven 3 feet into the ground, should safely stand pulls as under in good ground :—

Single picket	7 cwts.
1—1 picket holdfast	14 ,,
2—1 ,, ,, ...	1 ton.
3—2—1 ,, ,, ...	2 tons.

Unless the ground is very soft the strength of the pickets will generally be the ruling factor. For pulls greater than 2 tons a log may be used in conjunction with a series of 1—1 picket holdfasts. (Pl. XXXIII, Fig. 8.) This should safely stand 12 cwts. per holdfast. There should be the same number of holdfasts on each side of the cable, and they should be symmetrically arranged with respect to the cable. Care must be taken that the log bears equally against all the pickets in the front row. The log should rest on the ground and sufficient soil be removed to allow the cable to be passed round it. Sometimes the log is raised on packing to allow the cable to be passed round it more easily; but this is a dangerous practice, as it largely increases the stress on the pickets. The rear edge of logs of square section should be sunk in a shallow trench to give them a fair bearing on the pickets. This also lowers the centre of pressure on the pickets.

Rock holdfasts.

In rock or masonry, similar holdfasts can be made by drilling or jumping holes, into which crowbars are jammed as tightly as possible. Wire ties can be used for the backing up lashings, or a short length of chain with some tightening arrangement, such as a screw link. The heads of the crowbars should be set up to prevent the ties slipping off, in case the bars bend. Bent bars (Pl. XXXIII, Fig. 7) are stronger than straight bars. The leading bar should be about the same diameter as an iron wire rope strong enough for the given stress, provided the rock is sound enough. When the rock is not very sound or when large enough crowbars cannot be obtained the arrangement shown in Pl. XXXIV, Figs. 1 and 2, may be used. Holdfasts erected on a pier or masonry escarp will sometimes have to be made on a vertical face. (Pl. XXXIV, Fig. 3.)

Drawing pickets.

In drawing all pickets and crowbars, care should be taken that they are drawn out in the same line as that in which they have been driven, otherwise they are apt to be broken. Heavy pickets may be drawn with a light gyn or with a lever cart or with jacks. 5-foot pickets are generally drawn with lever as follows:—Pass a clove hitch on a soft rope or on a chain round the lever and pickets, take in the slack and pass the ends round the pickets in opposite directions two or three times, twist them together and hold on while the lever is lifted, the fulcrum being in rear of the pickets. Pickets should never be loosened by hitting them sideways with a maul.

Anchor piles.

14. Stout pickets may be driven under water in the following manner, and form what are known as "anchor piles" (Pl. XXXIV, Fig. 9):—The head of the picket or pile is fitted into a sort of "dolly," which is made of a spar, to the foot of which is spiked a metal socket.

The spar must be of such a length that its head is always a convenient height above the water level.

The socket may be formed of stout iron piping and should project about 5 or 6 inches from the foot of the spar. The head of the picket or pile should be slightly rounded to fit the socket loosely. About 15 inches down it is bored to take a "grummet," or spliced loop of rope, 2 feet long.

The end of the cable which is to be attached to the anchorage is passed down through the grummet, up alongside of the spar, and tied with a bowline to its standing part at the same level as the top of the spar. Both parts of the loop formed in the cable must be lashed to the spar near its head to prevent the picket or pile dropping out of the socket while being lowered.

The picket or pile is driven by blows from a maul, or pile driver, on the head of the spar.

After the pile has been driven up to the head or deeper in soft mud, the cable is cast off from the spar, and the latter is hauled up by a rope secured near its head.

Piles 4 inches in diameter and 3 feet 6 inches and 4 feet long

have been driven in from 10 feet to 14 feet of water in five or six minutes. Such a pile, when hauled on at an inclination of 1 : 10, has stood a pull of 5 cwts.

15. The best form of anchorage for heavier pulls is some arrangement of logs buried horizontally, with or without the addition of sheeting to distribute the pressure. Buried anchorages.

The strength of such an anchorage should be considered from two points of view :—

I. That of the log itself, which must be strong enough against cross-breaking, or shearing, at the cable. The calculations for this are similar to those already considered in Sec. IV.

II. The resistance of the ground must be sufficient to withstand the pressure that will be brought upon it. For this purpose it is best to consider the surface exposed to the earth as split up into a series of horizontal strips, each strip about a foot wide.

The resistances offered by different types of earth depend upon a variety of factors. The following expression embodies the results of experiment :—

$$r = \frac{1}{s} wd^2 . h . \sin 2\, \phi\, (1 . 5 - \sin \alpha)$$

Where—

r = safe resistance in lbs. per square foot.
s = factor of safety.
w = weight of earth in lbs. per cubic foot.
d = mean depth of anchor beam in feet, measured perpendicularly to surface of ground.
h = vertical height earth will stand when freshly cut.
ϕ = angle of repose of earth.
α = inclination of pull to horizontal or, on sloping ground, angle between cable and ground surface.

This expression is given in the form of a chart (Pl. XXXV), from which the necessary figures can be taken.

The holding power is reduced if the soil becomes wet. This can be allowed for by reducing the height at which the earth will stand vertically.

It has been found by experiment that the holding power of an anchorage made of round or half-round timber is the same as that of one made with square timber, the length of one face of which is equal to the diameter of the round timber, and that when the face of the anchorage is several feet deep the total resistance is not less than the sum of the resistances of each foot in depth. The simplest form of an anchorage of this description is a single log buried horizontally in the ground. (Pl. XXXIV, Fig. 6.) An anchorage of a bundle of logs is nearly as simple. (Fig. 8.) The cable or ties are taken round it and brought up to the surface.

The face of the trench should be as nearly vertical as possible, and the trench should be about 2 feet longer than the anchor log. The log is placed on short poles over the hole, lowered with ropes, and the earth filled in over it and rammed, except at the places where the cables will come. These are kept open by walls of sods or sandbags, and grooves to the rear as well will make it easier to pass stiff cables round the anchorage, though light cables may be passed round before the log is lowered. These cable trenches may be filled in when the bridge or whatever it may be is completed, though it is often more convenient to keep them open for subsequent adjustment. If filled in, the roadway over the excavation can be made good with fascines and protected as far as possible from the draining in of surface water. The width of the cable trenches must be added to the calculated length of the anchor log, for these portions will offer no resistance. In the chart (Pl. XXXV) this allowance is already made. When the cables are of hemp they should, if buried, be protected by being tarred or served with tarred canvas.

If the anchorage is required for any length of time, it is better to substitute an iron girder, an old gun, or a reinforced concrete beam, for the log, which is liable to rot, and to bring iron tie rods to the ground level, as these do not offer such a large surface to rust as a steel cable.

In all cases the corners of the log should be rounded or packed in some way, to avoid making a sharp bend in the cables. The rule given in para. **35**, Sec. IV, should be used.

Composite anchorages.

When great holding power is required, an anchorage consisting of a sheeting of planks or logs, resting against posts inclined so as to be at right angles to the direction of the pull, is best. Behind these posts is a large beam, to which the cables are secured, and which distributes the pressure along the posts. The position of this beam should be such that the resistance of the earth above and below it may be equal. (Pl. XXXIV, Figs. 4 and 5.) Should it be necessary to construct a holdfast of this nature when only a short baulk is procurable, three or four large planks may be laid in front of the baulk to distribute the pressure.

If the soil is wet with small holding power, it may be necessary to form an anchorage as follows :—Two baulks are bolted near the feet of the posts, which may afterwards be driven till stopped by the baulks. These baulks keep the posts from lifting. Horizontal sheeting is now put down, which, in some cases, it may be necessary to face with hurdles, planks or sheet piling. The heads of some or all the posts are supported by props, which butt on broad footings. (Pl. XXXIV, Fig. 7.)

The following table has been prepared as a guide to the holding power of common earth, on the following assumptions :—

Weight of earth, 90 lbs. per cubic foot; angle of repose, 30° ; 5 feet standing height when freshly cut; factor of safety.

16. Table of the holding power of dry loam earth :— Holding power in loam.

Mean depth of Face of Anchorage below Surface.	Inclination of the force drawing the anchorage (in a direction perpendicular to its face), and corresponding safe resistance in lbs. per square foot of anchor-face.				
	Vertical.	$\frac{1}{1}$	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{4}$
1 foot	70	110	150	160	175
1 foot 6 inches ...	150	250	320	360	390
2 feet	290	410	580	650	700
3 ,, ...	600	950	1,300	1,450	1,500
4 ,, ...	1,050	1,750	2,200	2,600	2,700
5 ,, ...	1,700	2,800	3,600	4,000	4,100
6 ,, ...	2,400	3,800	5,100	5,800	6,000
7 ,, ...	3,200	5,100	7,000	8,000	8,400

After the soil became wet the holding power was observed to be somewhat lessened.

The following example will show the method of use of this table :— Examples.

How deep must a log 18 feet by 15 inches be buried in good ground in order to safely resist a tension of 63,000 lbs. ?

The effective length of the log in resisting this pull will be that portion which bears against the face of the excavation and the length of timber which lies across the grooves, for the cables must be deducted from the total length of the timber. These grooves will probably be 1 foot 6 inches wide each, so that the effective length of the log is 15 feet.

The area of the face of this log is therefore $15 \times \frac{5}{4}$ square feet,

and the pulling force per square foot is $\frac{63000 \times 4}{15 \times 5} = 3{,}360$ lbs.

Assuming that the cables slope at $\frac{1}{2}$, we find on referring to the table that a mean depth of 5 feet is required, giving a safe resistance of 3,600 lbs.

If the slope of the pull was $\frac{1}{2 \cdot 5}$, the approximate resistance per square foot to a tension at this slope could be obtained from the table by taking the mean between the figures given under $\frac{1}{2}$ and $\frac{1}{3}$.

This table may also be used to determine the ultimate resistance of an anchorage of the pattern shown in Pl. XXXIV, Fig. 4. In this case the holding power of each horizontal log should be ascertained separately, and the sum of these values will represent the total holding power of the anchorage.

Anchorages on rocky ground.

When shallow soil overlies disintegrated rock there may be insufficient holding ground for pickets, or for a sunken beam holdfast constructed in the usual manner, and the underlying rock, although too shaly or split to hold crowbars, may yet be too hard to admit of excavation.

In such cases the difficulty may be met by sinking a long and strong beam as far as practicable—say, its own depth—in the surface soil, and keeping it from rising by laying a platform of planks over it and weighting it down with sandbags, earth, rocks or any available material. The beam, so long as it is kept from rising, will exhibit great holding power.

An anchorage of a similar nature, but a little more elaborate, consists in securing the individual bridge cables to thimbles, which are threaded on a steel bar. On this same bar, and alternately to the thimbles, are threaded the eyes of a number of wrought iron rods, about 10 feet long, and having other eyes at the other ends, but turned at right angles. Through these eyes are placed vertical jumpers bedded in a mass of rough masonry.

Anchor holdfasts.

Sheers and so forth have sometimes to be employed on sea fronts under circumstances when it becomes necessary to make use of anchors, laid out as moorings for the fore guy.

To obtain a reliable holdfast under these circumstances, it is necessary to consider the following points :—

I. The nature of the holding ground.
II. The number and size of the anchors available.
III. The stresses to be provided against.

The further out the anchors are laid the more horizontal will the stress be that comes on them, and consequently the less the probability of their being lifted from their bed. The exact spot where each anchor is to be let go should have been decided upon beforehand and buoyed.

To guard against the anchors falling over on their side and so failing to take hold, a handspike may be lashed to the stock.

It is well to let the anchors remain under water for a day after being laid out before putting a stress on them, in order to give them time to settle down.

Chain cables are preferable to rope for making fast to anchors, especially where the ground is foul or rocky. The shore end of the cable to which the fore guy of the sheers has to be attached should be buoyed until required.

This form of holdfast is not very reliable, and when used with sheers inward heel should be avoided when possible. The safe holding power of anchors is dealt with in Sec. VII of Part IIIB. A stress one and a half times as great as the maximum liable to be thrown on the anchors should be exerted on the moorings by means of winch power before they are taken into use. This will serve as a test and will also make the anchors take hold.

Anchors used as holdfasts not under water can be secured

by burying one fluke, and placing a baulk inside the crown at right angles, and driving pickets in front of the baulk. This arrangement may be further strengthened by driving pickets in front of the stock.

Use of Spars.

17. Derricks, sheers and gyns are used for raising weights from the ground, either for the purpose of taking them from or putting them into boats, carriages and so forth, or of changing their position, particularly in girder erection. A gyn allows a vertical lift only; sheers allow the weight to be lifted and moved along a straight line from front to rear, or conversely; a derrick allows it to be lifted and moved to the right or left, as well as to the front or rear. Introduction.

For more detailed descriptions of these machines, and for the precautions that should be adopted in carrying out any heavy work of this nature, reference should be made to "Garrison Artillery Training, Vol. III."

The cubic contents and the weight of any spars that are to be used, whether square or round in section, can be obtained as described in para. 7, Sec. III. If no lever cart is available for carrying them they may be carried by men, the number required being reckoned by assuming each man to lift about 56 lbs. The men should be sized by the shoulders and arranged on alternate sides of the spar, being closer together at the butt. The spar should be lifted by word of command, and lowered in the same manner, the butt being lowered first. Common details.

The length of spars for any of these machines will depend on the height to which the weight has to be raised; and in the case of derricks and sheers, on the distance from the base at which the weight has to be picked up. But their length should be kept as small as possible, as the tendency to buckle is thereby reduced. It must not be forgotten in this connection that the tackle employed will occupy about 4 to 5 feet, even when chock-a-block, in addition to any sling.

18 Guys should be secured by clove hitches to tips of spars. When long ropes are available the clove hitch may be in the centre, and the rope thus act as two guys. The best position for the guy holdfasts on level ground is at a distance equal to twice the effective length of the spars from the base. When the ground is not level the position of the holdfasts should be so chosen that the slope of the guys remains the same as this—namely, 1 : 2. (Pl. XXXVIII, Fig. 4.) Guys that are attached to anchor holdfasts should, however, be at a flatter slope, not more than 1 : 3.

A distinction can be made between "running" guys—that is, guys on which the weight will come during the operation—and those which are only necessary for the stability of the machine. In the case of the former, with heavy lifts it is an advantage to

have them of steel wire rope, as this does not stretch so much under a stress as cordage of the same strength. Every running guy, in all but the very lightest lifts, should be composed of a tackle, the arrangement depending on the weight to be dealt with. This should be the case, even when the weight has only to be lowered by the guy and not lifted. If the hook of the block of the tackle is placed in a bight of another part of the guy, this bight should be protected by a thimble.

Protection of this nature should always be given to a rope which would otherwise make a sharp bend, if not, the rope loses one-quarter to one-third of its strength. The guys should be secured to the head of the spars as nearly opposite one another as possible, and as near to the position of the sling or lashing of the lifting tackle as can be managed, to avoid transverse stress in the spar. For the same reason the leading block of the tackle should be as near the foot of the spar as possible.

Foot-ropes will generally be required as a precaution in raising these machines, and, if a sound footing cannot be obtained in the ground, they will also be required while the machines are in use, especially when they are heleed over. For heavy spars it is better to use tackles for these foot-ropes. In all cases where foot-ropes are employed, they should be attached as near the point of rotation as possible, so that the alteration in their length that has to take place during the operation of raising may be reduced to the minimum.

The footings under these machines must be firm. To prevent the butts slipping sideways after they are raised, they are generally sunk in a hole about 1 foot deep. On soft ground, and where heavy weights are to be lifted, the pressure on the butts should be spread over a larger area by resting them on cross baulks or on shoes. In this case the butts should be kept in their place by wooden cleats nailed to the baulks all round them.

Standing derrick.

19. A derrick or standing derrick is a single spar with the butt on the ground, and the tip held steady in the air by ropes or guys, of which it usually has four at right angles to each other in plan. The block of the tackle may either be lashed to the spar or suspended by a sling passing through a slot in the head of the spar. The fall passes through a leading block lashed to the derrick near the ground. (Pl. XXXVI, Fig. 1.) A light cross-piece lashed to the spar below the sling attachment will keep the tackle clear of the spar.

To raise a light derrick the spar is laid in the line from the footing to one holdfast with the butt nearly over the footing, and a foot-rope secured to the butt and to a holdfast on the same side of the footing as the spar and close to it. The four guys having been made fast to the tip and passed to their holdfasts, the tip is lifted as high as possible by hand, and, if necessary, supported after each lift by a light frame, which is moved gradually from the tip towards the centre of the spar. The back guy is

then hauled on, with a runner tackle if necessary, and the fore guy let out, until the derrick is in the desired position. The side guys will have to be watched and adjusted; but if the lines joining the side holdfasts with the butt are exactly at right angles to the line joining those of the fore and back guys, the side guys will never need to be shifted.

If a derrick is too heavy to be lifted by hand to the height at which the guys can be effectively used, a lever must be used, as shown in Pl. XXXVI, Fig. 2. The lever is lashed to the guy by taking a number of turns round the tip of the lever and the guy and ending in a draw knot, the lashing being prevented from slipping down by a collar of rope. A long loose end should be left so that the draw knot may be pulled out from the gound level; or, better still, by beginning with a clove hitch on the lever above the proposed lashing, and then passing round lever and guy with a succession of draw-knots formed from bights of rope. The lever must be provided with side guys, or it may fall sideways. The tip of the lever is then raised into the position shown in Fig. 2, the butt being close to the derrick. The pull on the guy will thus raise the tip of the derrick. When the lever is of no further use it will begin to rise off the ground, and should then be released from the guy by pulling the loose end of the lashing. Pl. XXXVII gives, for different proportions of derrick and lever, the length of guy that should be left between their tips and the distances between their butts. It also shows the maximum pull required on the guy and the greatest stress in the lashing at the tip of the lever.

For heavier derricks still a light derrick or pair of sheers must first be erected near its tip as it lies on the ground.

Derricks can be erected in one place and moved or "walked" to another, the guys being carefully adjusted and the foot moved if necessary with foot tackles and checked by other foot-ropes. The safe limit of incline for derricks when in use is 3 : 1; but when first raised they should not be at a flatter slope than about 5 : 1, as when the guys stretch the slope will become the limit of safe working. This limit of slope regulates the distance at which a weight can be picked up by the derrick, and if this distance is fixed the minimum height of the derrick is thereby determined.

20. Sheers consist of two spars with their butts apart on the ground and their tips lashed together and held steady in the air by a fore and back guy. A load lifted by sheers can be swung through between the legs by letting out the fore guy and hauling on the back guy, the fore guy being let out very cautiously as the sheers become nearly vertical. The fore guy may sometimes be dispensed with when necessary, as when loading a boat at a wharf or pier; but in this case the sheers must always have a distinct lean outwards. Sheers are simpler to use than standing derricks, only requiring two holdfasts and guys, and do not require such heavy spars; but they can move a weight in a straight line only. Sheers.

To make sheers, two spars are laid with their butts flush together on the ground, but supported on a baulk near their tips. A clove hitch is then made round one spar about 3 feet from the tip, and the rope is taken loosely six or eight times round both spars above the clove hitch without riding. The lashing is then frapped two turns, as in Pl. XXXVI, Fig. 3, and the end of the rope is made fast to the other spar by two half hitches just above the lashing. Any spare end to the rope may afterwards be got rid of by winding it round one of the spars. The butts of the spars are then opened out till their distance apart is about one-third the length of the spars from butt to lashing, and a sling is passed over the fork, as in Pl. XXXVI, Fig. 4. With large spars the feet should be separated to nearly their full extent before lashing, as otherwise the lashing is tautened too much. If the tackle is heavy it need not be hooked into the sling at first, but a whip must be secured near the tip of one of the spars, by which it can afterwards be raised. In securing the rope of the whip to the block of the main tackle for this purpose, it should be bent on the eye and not to the hook. The hook will then be free to be hooked into the two parts of the sling when raised, which would not be the case if the whip were made fast to the block itself. With large sheers, cleats for getting up to the top should be nailed to one leg. The legs should be prevented from splaying by tying them together, preferably by a ledger lashed near their feet, and footings must be prepared. The guys are made fast near the tips by clove hitches, in such a way that they will draw the spars together when the stress comes on them—that is, the fore guy to the rear spar and the back guy to the front spar. With very heavy sheers it is sometimes advisable to put the guys right round the lashing.

Sheers are raised in the same way as derricks. Up to 35 feet in length they can be raised by a lever, but heavy sheers are best raised by means of a derrick between the legs.

Sheers can be walked after erection in a similar manner to derricks, the same precautions being adopted. The limit of their working slope is also the same, 3 : 1, with the same restriction to a slope of 5 : 1 when first erected.

Gyns. **21.** A gyn consists of three spars lashed together at the tips, the butts forming an equilateral triangle on the ground. It requires no guys, but can only be used for a vertical lift.

To make a gyn, the spars are first laid with butts flush and then marked at the place where the centre of the lashing will be. The two outer spars are then left where they are, rather farther apart than their own diameter, while the third spar is laid between them so that the marks on the three spars are in line, tips resting on a baulk, but with its butt in the opposite direction.

A clove hitch is made on one of the outside spars and the lashing taken over and under the three spars loosely six or eight

times; the lashing will then appear as in Pl. XXXVI, Fig. 5. After which a couple of frapping turns are taken round the lashing between each pair of spars in succession, and finished off with two half hitches on the other outside spar. The two outer spars are then crossed till the butts are at a distance apart equal to about half the length of the leg, and a ledger or light spar is lashed across these two spars at about 1 foot from the butts.

To raise the gyn, the head is lifted as far as possible by hand, and the centre spar or prypole brought in towards the centre of the ledger already fixed, either by a handspike lashed across it or by tackle. If the other end of the tackle is attached to the ledger first fixed, this must be allowed for in determining the necessary diameter of this spar. When the butts form an equilateral triangle two more ledgers are fixed on, so as to prevent the legs from shifting. A sling can now be passed over the lashing at the head if it has not been put on during the process of lifting. If the lashing at the head has a tendency to slip down the legs of the gyn during its erection, a stout nail driven temporarily into the leg will prevent its doing so.

22. A swinging derrick consists of a standing derrick with a swinging arm attached to it near its foot. The tip of this swinging arm is connected to the upright spar by a connecting tackle, and the main or lifting tackle is attached to the tip of the swinging arm or jib. (Pl. XXXVI, Fig. 6.) The upright spar is practically the same as a standing derrick, with the exception that as it will frequently be erected at the edge of a wharf or other place where it is not convenient to use a fore guy, a strut or struts must be used instead. A good method is to use two struts, each about half as long again as the upright spar, lashing the three together as in a gyn and then to erect it so that the standing derrick is vertical and the two struts are at right-angles in plan, and situated symmetrically with respect to the edge of the wharf. Two guys can also be used, one over each strut in plan, but secured to holdfasts at the customary distance; or three guys can be used, one a back guy and the other two side guys, but set back about 20 degrees from the edge of the wharf, to allow room for the loads to be landed. It is important that these guys should not stretch too much, so that the upright spar may remain vertical. It is therefore better to make them of wire rope, and in any case a tackle should be included in them to take up any slack. (Pl. XXXVIII, Fig. 1.) The stress in these guys is much greater than that in guys for a standing derrick to deal with the same weight. Swinging derrick.

The jib is most conveniently formed of two spars, lashed together at their tip, and separated at their butts to a distance about equal to the diameter of the upright spar. They are lashed about 1 foot or 18 inches from their butts to a stout cross-piece, and the end thus formed encircles the butt of the upright.

(Pl. XXXVIII, Fig. 1.) The jib is supported by a length of chain, secured at its centre by a clove hitch round the upright and prevented from descending by a collar of rope, and each end secured to one of the arms of the jib. The latter is enabled to swing, under the control of two side guys or reins attached to its tip. The length of the jib may be of the same length as the upright. The inclination of the jib can be altered by the connecting tackle, and the radius of its circle of operation is thus determined. The weight can be lifted or lowered by the main tackle and the jib swung by the reins. The jib can only be swung right over the edge of the wharf on that side of the upright on which are the leading blocks of the main and connecting tackles. If it is necessary to swing both ways, duplicate leading blocks for the falls of these tackles must be provided. If one spar only is available for the jib it should be fastened to the upright spar, as shown on Pl. XXXVIII, Fig. 3.

It must be noted that the weight must be allowed to hang vertically from the tip of the jib. If it is hauled towards the butt of the standing spar, the thrust on the jib is greatly increased; and if it is hauled away from this butt, the stresses in the back guy and connecting tackle are largely increased. If the weight has to be brought in otherwise than by swinging to a flank, it should be done by raising the head of the jib by means of the connecting tackle.

Lever sheers.

23. Lever sheers (Pl. XXXVIII, Fig. 5) can be used when only a vertical lift is required and when no fore guy can be used. They are formed by a crutch supporting a stout spar, which is anchored at the foot.

Back leg sheers.

It is sometimes convenient in heavy work, where no fore guy can be used, to employ sheers with a movable back leg to act as back guy and strut combined. The head of this leg is secured to the crutch of the sheers, and its butt is constrained in some way to follow a horizontal baulk on the ground, so that it is strong enough to withstand either a pull or a thrust. The butt of this leg can be moved inwards or outwards by means of tackles, and the heel of the sheers thus altered.

Gallows.

24. In girder erection it is often convenient to use a gallows, that is, a frame consisting of two upright spars, connected at their heads by a cross-piece, to which two or more tackles can be attached. Such a gallows will need side guys or other bracing, and also front and back guys. They are commonly used in pairs, one on either side of the gap, and in this case a connecting guy can be used as the fore guy of each of them. In cramped situations, such as the top of an embankment, where there is no room for ordinary bracing, the cross-piece may be long, and bracing taken from the ends of that to the butts of the uprights.

Calculations.

25. The design and details of stores required for a derrick, sheers or gyn, will depend on the weight and the height to which it is

to be lifted, and will also vary according to the stores obtainable. In any particular case, after the design and length of the spars has been determined, the stresses in the individual members can best be determined graphically. It must be remembered that the stress or thrust in any leg of a machine of these natures is increased by the tension of any fall whose leading block is lashed to that leg by the amount of that tension. For large jobs a special determination should be made of the stresses in the various members.

The following table gives the stresses in terms of the weight lifted by the main tackle in the various members under the worst conditions obtaining in practice. These figures do not include an allowance to convert the live load into its equivalent dead load, but they do allow for the weight of the tackle and so forth. In the case of the swinging derrick, the proportions of its members are assumed to be those given above, and any alteration in these proportions will affect them :—

Standing derrick—	
Spar	1·5 W.
Running guys	·5 W.
Other guys	·3 W.
Sheers—	
Leg with leading block	·9 W.
Other legs	·7 W.
Back guy	1·3 W.
Gyn—	
Spar with leading block	·6 W.
Other spars	·4 W.
Swinging derrick—	
Upright spar	2·0 W.
Swinging arm	1·3 W.
Struts	1·0 W.
Connecting tackle	1·7 W.
Guys	1·5 W.

When the stresses in the members have been determined the size of the guys can be readily found. In the case of the struts, however, their length has also to be taken into account, and for this purpose reference should be made to Pls. XII and XIII. Other portions of these machines will also need consideration, such as the lashings at the heads of sheers and gyns, the slings of the tackles, the lashings at the leading blocks and so forth. With regard to the last, it is possible to reduce the stress in them by suitably arranging the position of the motive power, as shown in para. 4, Sec. V. The leading blocks should be as near the butt

of the spars as possible, to reduce the transverse stress in the spars.

Where derricks and sheers have to be erected on ground which does not give satisfactory footings, it may be necessary to determine the horizontal thrust due to the load at the butts of the spars, so as to see what will be required in the way of foot-ropes. If there is any doubt as to the stability of the structure on which the shoe or butt rests, it will also be necessary to determine the vertical pressure on the footing.

The tackles to be used and the motive power for working them will need consideration.

Section VI.—ORGANIZATION OF WORKING PARTIES.

1. In military bridging, as in all other engineering work, success depends as much upon the administrative capacity of the engineer as upon his technical knowledge.

2. The ideal to be aimed at is that when the bridging operations have been commenced they should be carried through to completion without any check or delay.

In order that this may be accomplished the following points must receive most careful attention :—

(1) The design of the bridge must be that best suited to :—
- (*a*) The nature of the gap.
- (*b*) The material available.
- (*c*) The load to be carried.
- (*d*) The time and men available for work.

(2) The preparation of an accurate estimate of the materials required.

(3) Arrangements for transporting the material to the places where it is required at the proper time.

(4) The preparation of a programme of the order in which the work shall be carried out.

(5) An estimate of the labour required for each part of the work.

(6) A review of the operation in order to forestall any difficulties which may arise while the work is in hand.

3. In peace time, when time is no object, it may be possible to attend to these points before commencing work. On the other hand, on active service it will be found that work often has to be commenced at once, and that there is only time to make a very rough approximate estimate of the actual requirements.

In order that wastage of time and labour may be reduced to a minimum the points noted above should receive attention during the progress of the work.

4. The total number of men available is called the working party. The organization of the working party depends upon the number of hours which the construction of the bridge will occupy.

In an emergency men can work 12 hours at a stretch.

If required for longer periods they can work in alternate reliefs of 8 hours for 2 days.

Beyond this the working party must be told off into three parties for reliefs of 8 hours each, *i.e.*, 8 hours on and 16 hours off.

5. The sequence of the several operations of the work having been settled, and the working party having been told off into reliefs, the successful organization of the working party depends upon the proper subdivision of each relief into gangs.

Each gang will be composed of such tradesmen and labourers as may be required for their portion of work, and will be placed under a competent ganger, who is responsible to the officer in charge for the work of his gang.

6. By this arrangement the officer in charge is able to exercise general control over the whole work, and make such deviations from the original plan as he deems fit to meet emergencies as they occur.

7. Below will be found a table which gives the approximate amount of time and labour required to construct certain types of military bridges.

This table is based upon actual experience in the field, but can only be regarded as a very rough guide to the framing of approximate estimates of time and labour for such nature of work.

The estimate may be taken to include all work necessary in ordinary cases, but does not include heavy work connected with approaches.

The whole of the material required is assumed to be on the ground, at the site of the bridge.

TABLE P.

Type of Bridge.	Designed to carry—	Man-hours per foot run.	Maximum economical party.
Girder bridges	Infantry in fours ...	10	50
—	„ „ file ...	8	50
Cantilever bridges ...	„ „ fours ...	8	70
Trestle bridges	„ „ „ ...	7	60
Frame bridges—			
Single lock... ...	„ „ „ ...	3	30
Double lock ...	„ „ „ ...	4	50
Single sling ...	„ „ „ ...	6	70
Treble sling ...	„ „ „ ...	9	70
Suspension bridges ...	„ „ „ ...	12	40
—	„ „ file ...	10	40
Tension bridges... ...	„ „ fours ...	12	80
Pontoon bridges ...	„ „ „ ...	·75	100
Boat and barrel bridges	„ „ „ ...	4	60
Barrel bridges	„ „ single file	1	50

INDEX.

FORDS. Fig. 1.

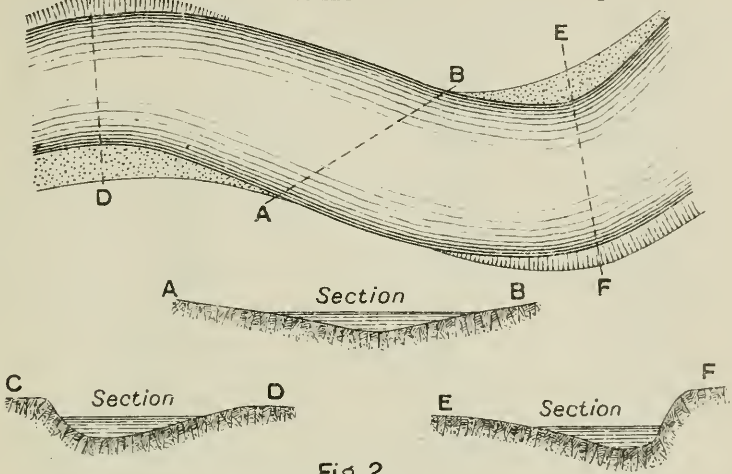


Fig. 2. SWIMMING HORSES OVER RIVER.

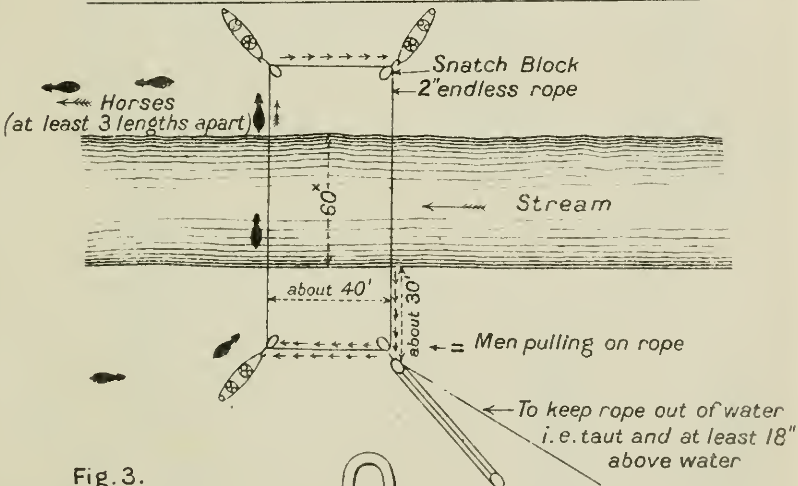


Fig. 3.

Knot for attaching
Head Rope to 2" endless
cable for swimming horses

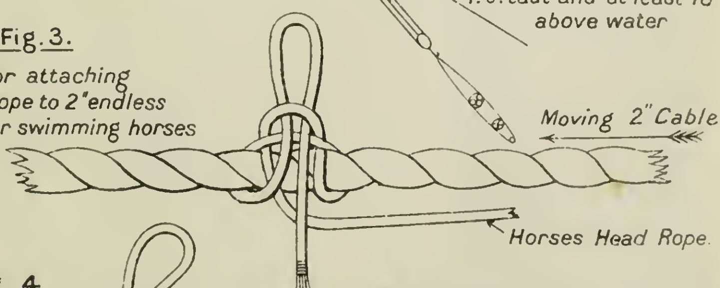
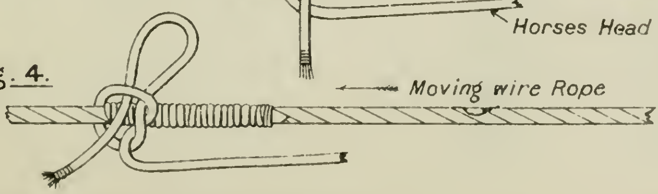


Fig. 4.



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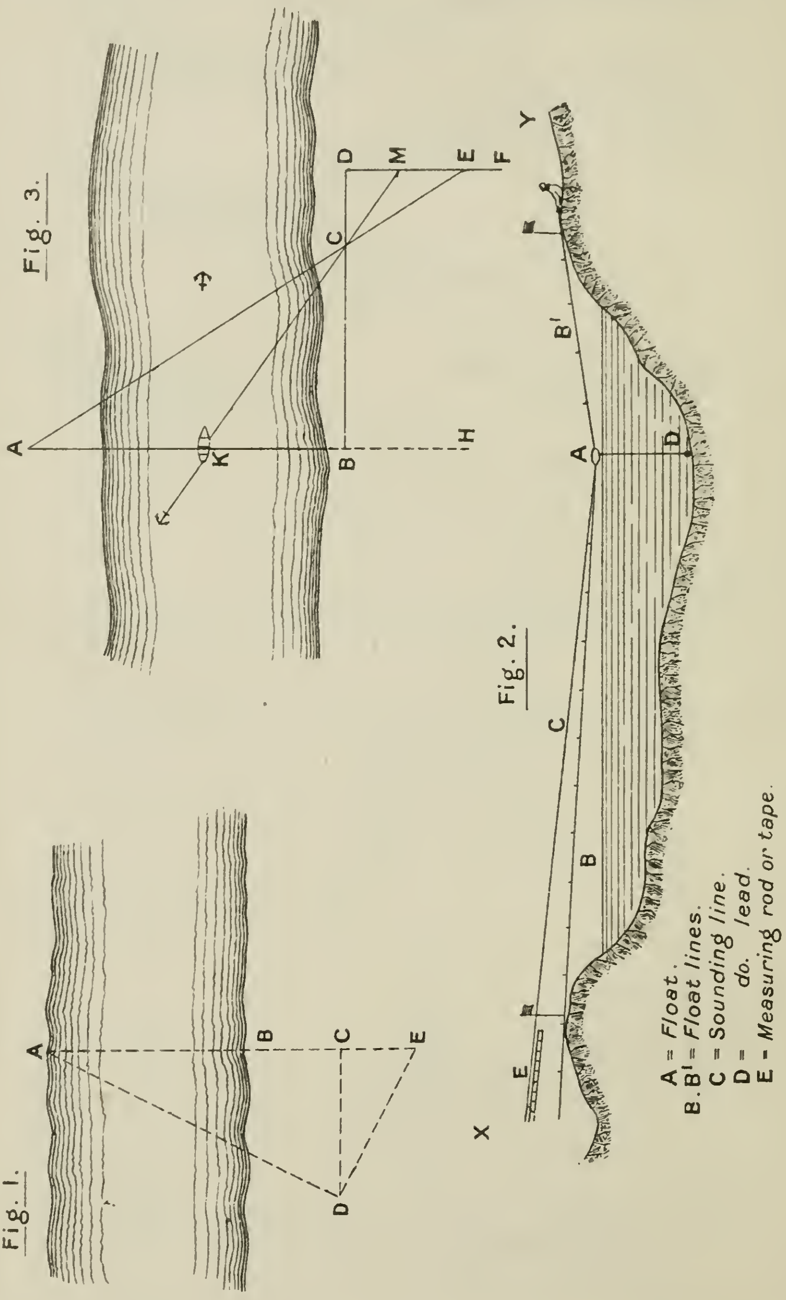
Measuring Rivers and taking Sections.



SUPERSTRUCTURE.

Fig. 1.

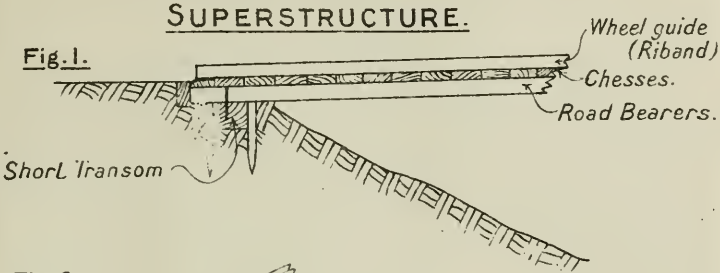


Fig. 2.

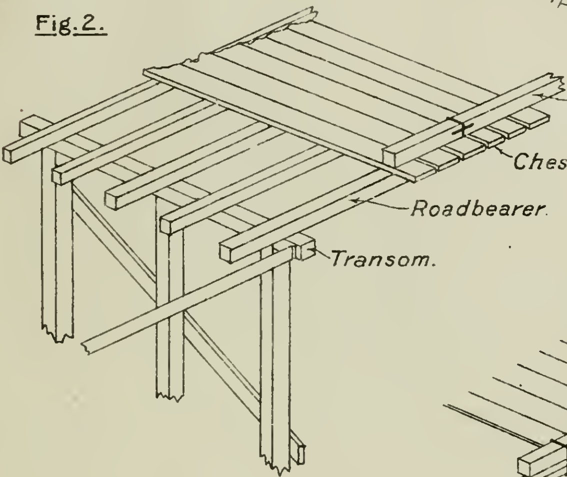


Fig. 3.

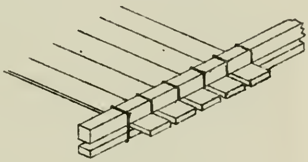


Fig. 4.

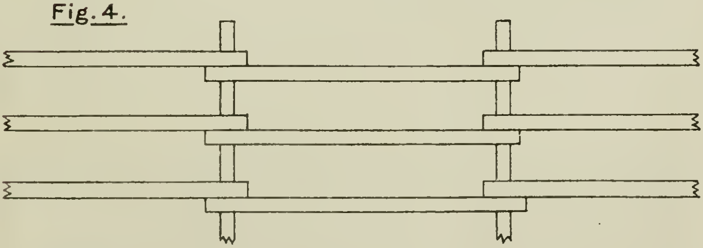
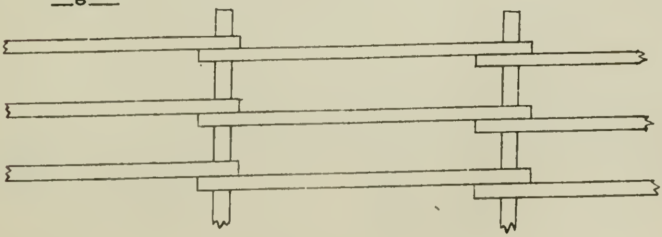


Fig. 5.



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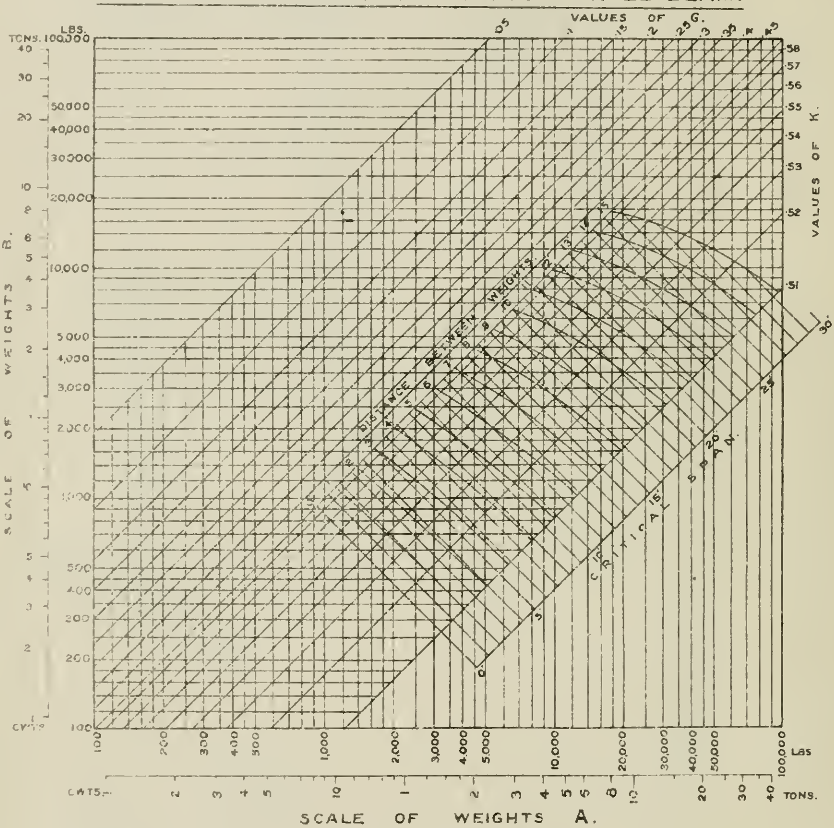
CRITICAL SPAN

FOR MAXIMUM BENDING MOMENT

PRODUCED BY A

PAIR OF MOVING WEIGHTS ON A SUPPORTED BEAM.



The Mfff always occurs under the Heavier Weight.
For spans less than the critical span, when it is at the centre of the span.
For spans greater than the critical span, when it, and the centre of gravity of the two weights, are at equal distances from the respective supports.

Enter the Chart by Scale A for the Heavier Weight and Scale B for the other weight.
From the intersection, run the eye parallel to the diagonal lines giving the value of K, until the curved line, representing the distance between the weights, is met.
From this point, carry the eye along the transverse diagonal lines to the scale of critical spans.

If the span in question is greater than the critical span, the position of the centre of gravity can be found by entering the Chart by Scale B for the Heavier Weight, and Scale A for the other weight.
The intersection gives the value of G. the distance of the centre of gravity from the Heavier Weight, expressed as a fraction of the distance between the weights.

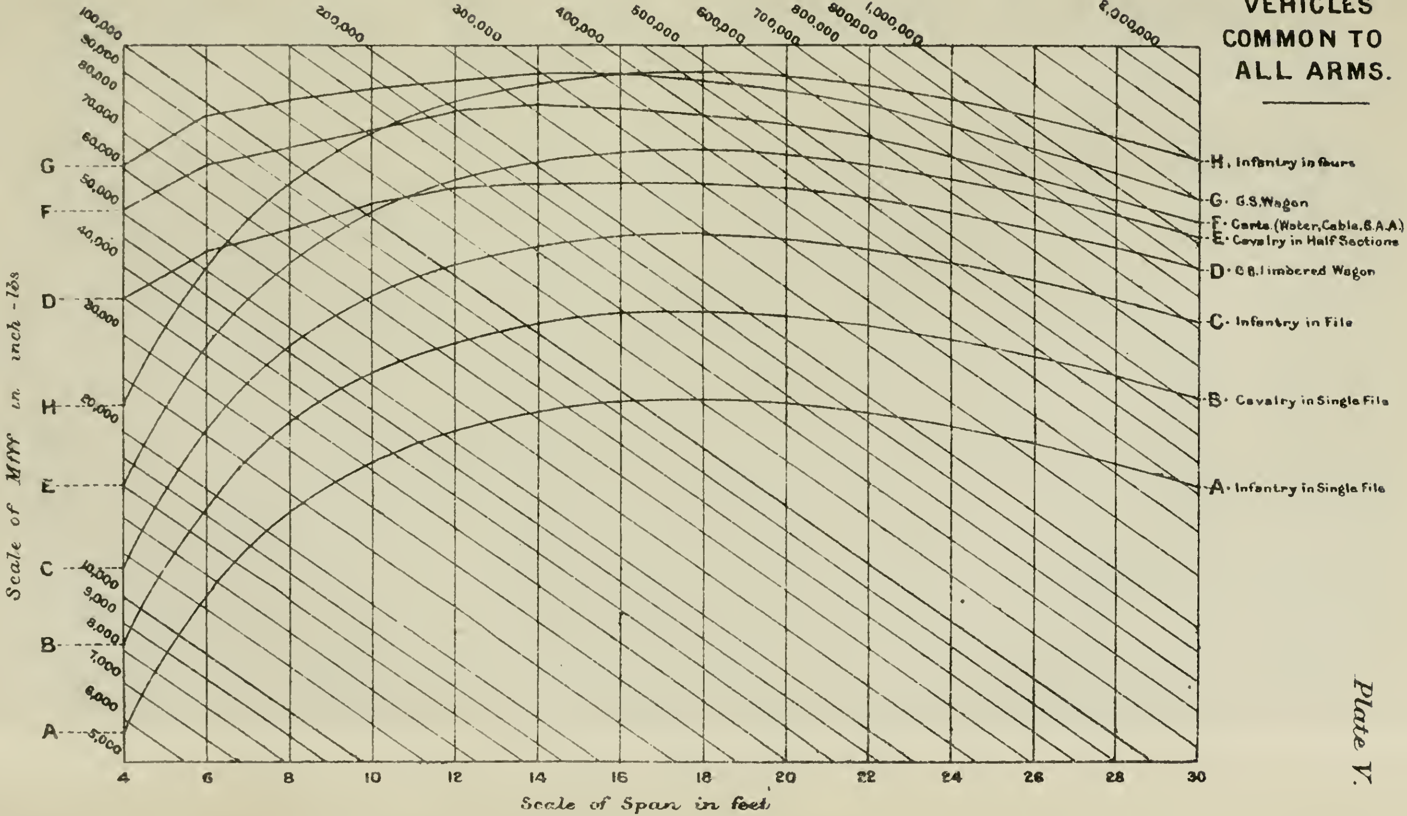
N.B.—$R = \dfrac{\text{Heavier Weight.}}{\text{Other Weight.}}$ $K = \dfrac{\text{Distance between Weights.}}{\text{Critical Span.}}$

$$K = 1 + R - \sqrt{R^2 + R}.$$

MAXIMUM BENDING MOMENT ON SUPPORTED ROAD-BEARERS.

TROOPS.

VEHICLES COMMON TO ALL ARMS.



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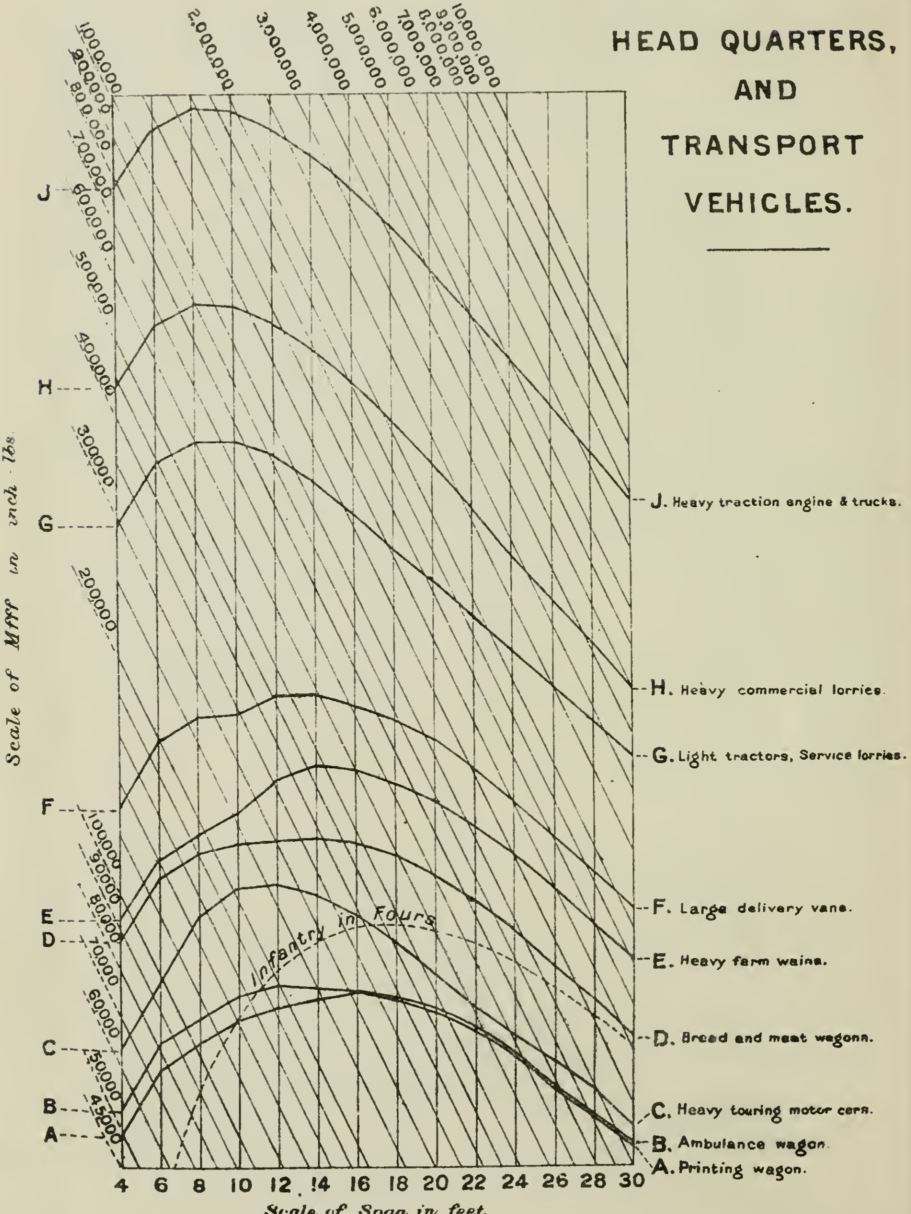
MAXIMUM BENDING MOMENT ON SUPPORTED ROAD-BEARERS.

Plate VI.



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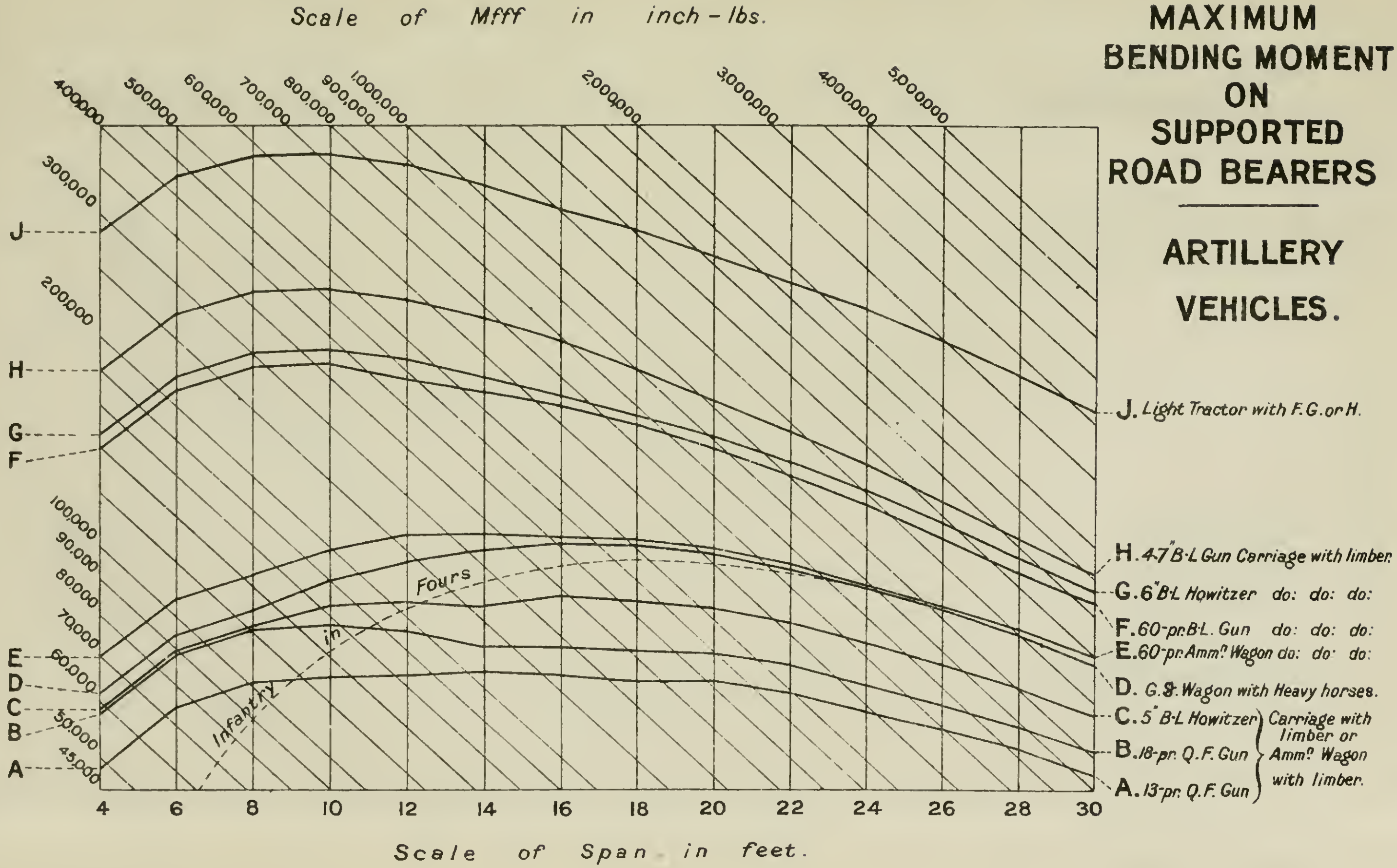
MAXIMUM BENDING MOMENT ON SUPPORTED ROAD BEARERS

ARTILLERY VEHICLES.



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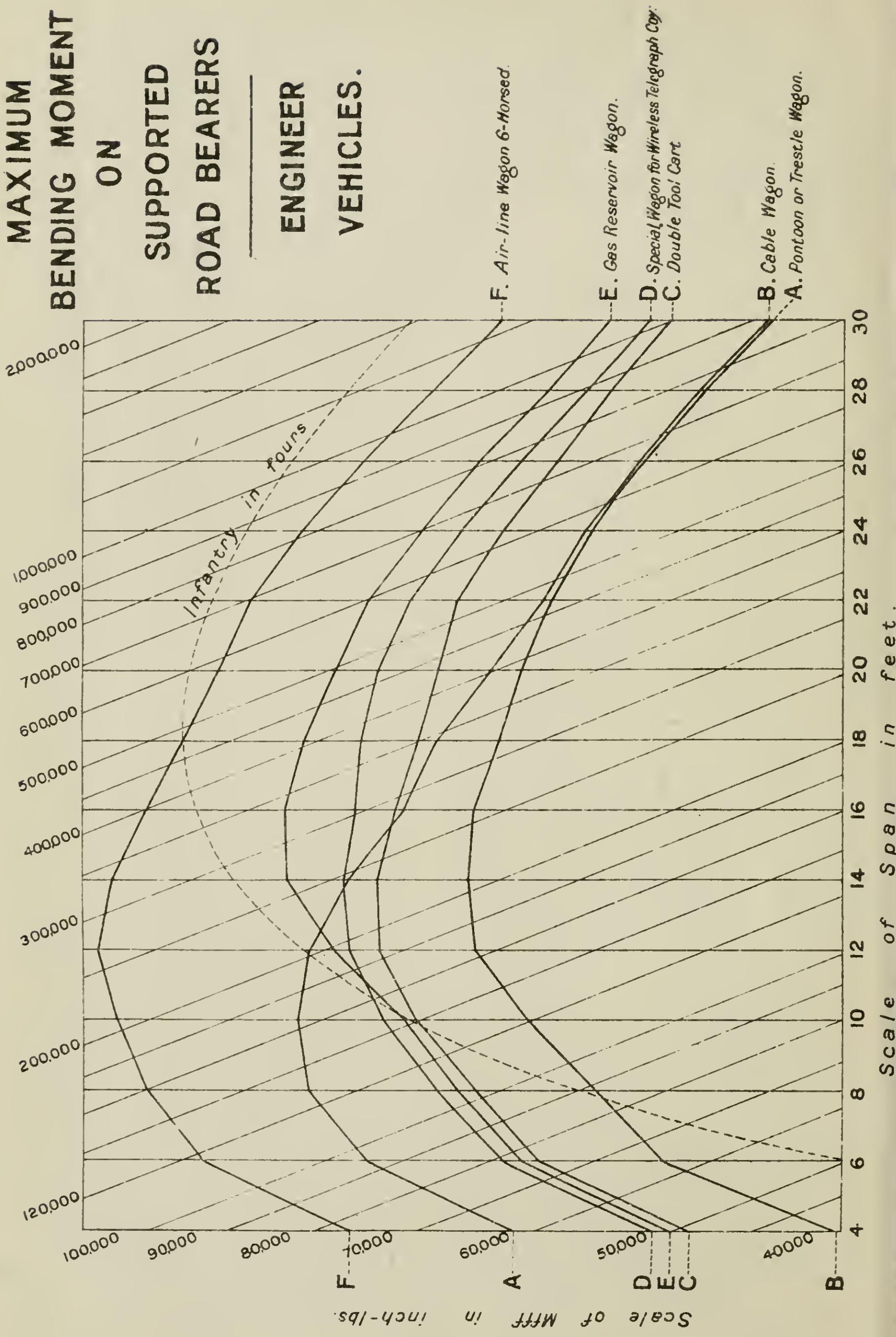

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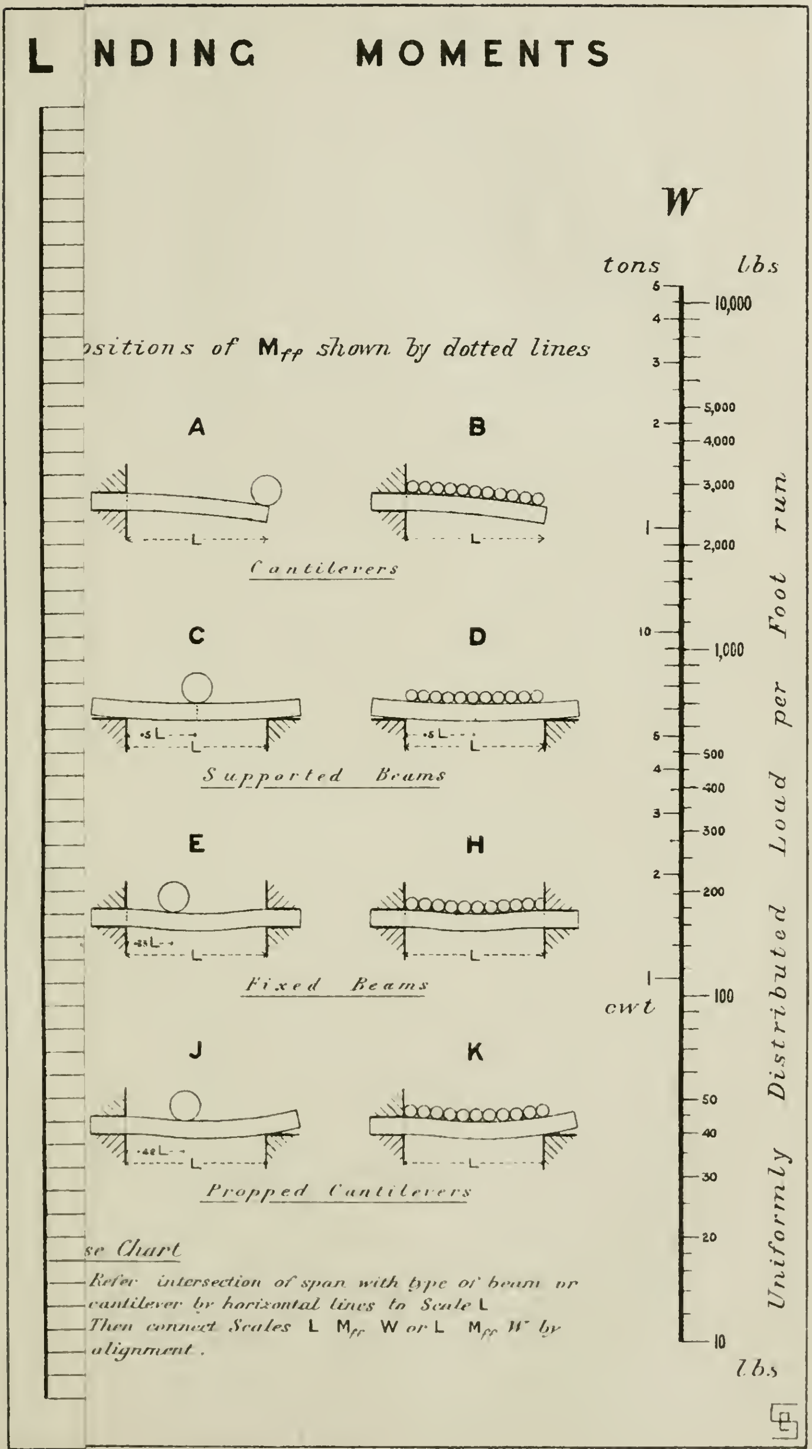
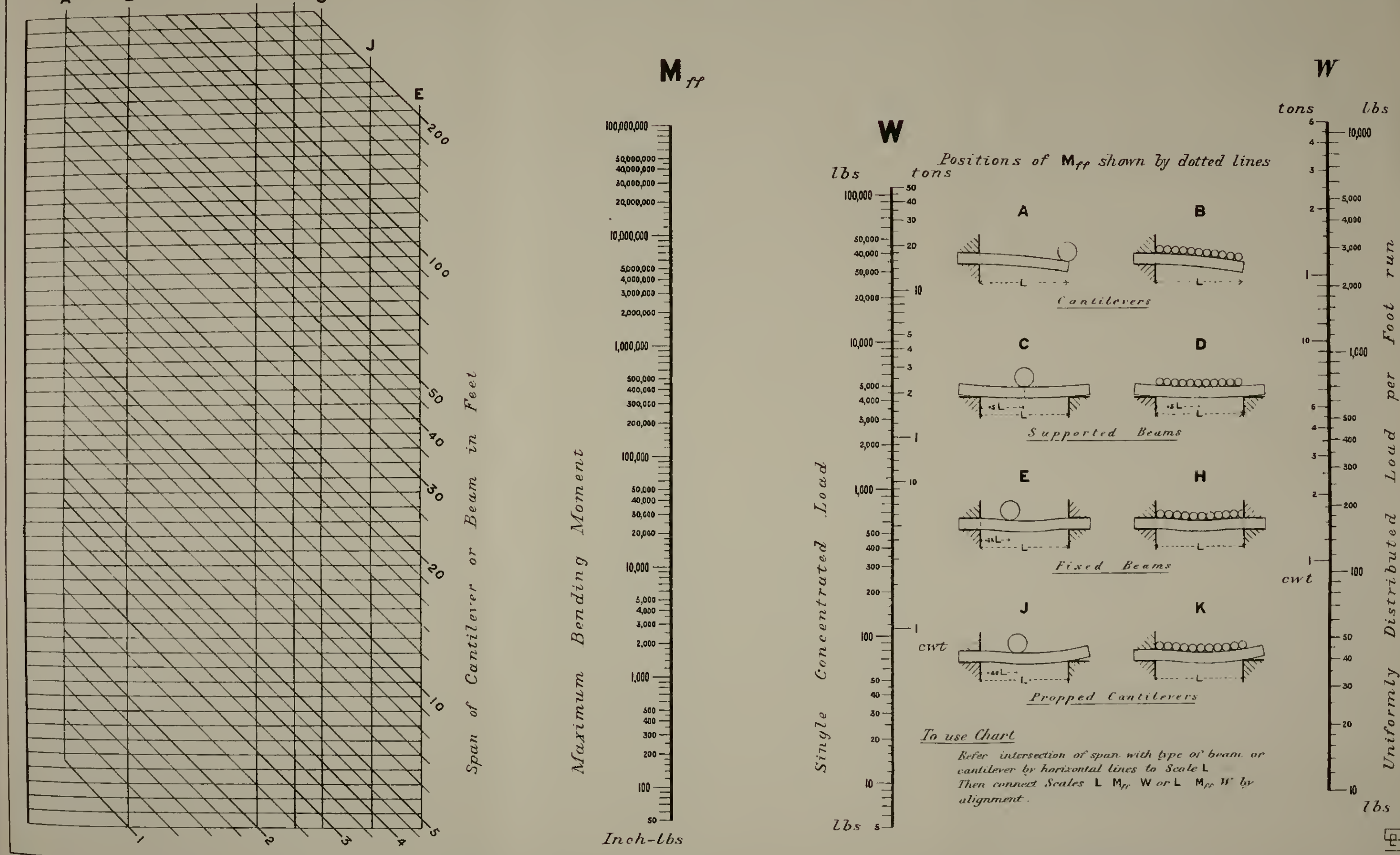

L NDING MOMENTS
W
tons
lbs
6
10,000
4
3
5,000
2
4,000
3,000
1
2,000
10
1,000
5
500
4
400
3
300
2
200
1
100
cwt
50
40
30
20
10
lbs
Uniformly Distributed Load per Foot run
ositions of M_ff shown by dotted lines
A
B
L
L
Cantilevers
C
D
•5L
L
•5L
L
Supported Beams
E
H
L
L
Fixed Beams
J
K
L
L
Propped Cantilevers
se Chart
Refer intersection of span with type of beam or
cantilever by horizontal lines to Scale L
Then connect Scales L M_ff W or L M_ff W by
alignment .

MAXIMUM BENDING MOMENTS



MENTS OF RESISTANCE

$= r \frac{I}{y}$ Section Modulus $Z = \frac{I}{y}$

To use Chart — Refer Section Modulus of required beam to Scale **Z**. Then connect **Z**, M_r, and r by alignment.

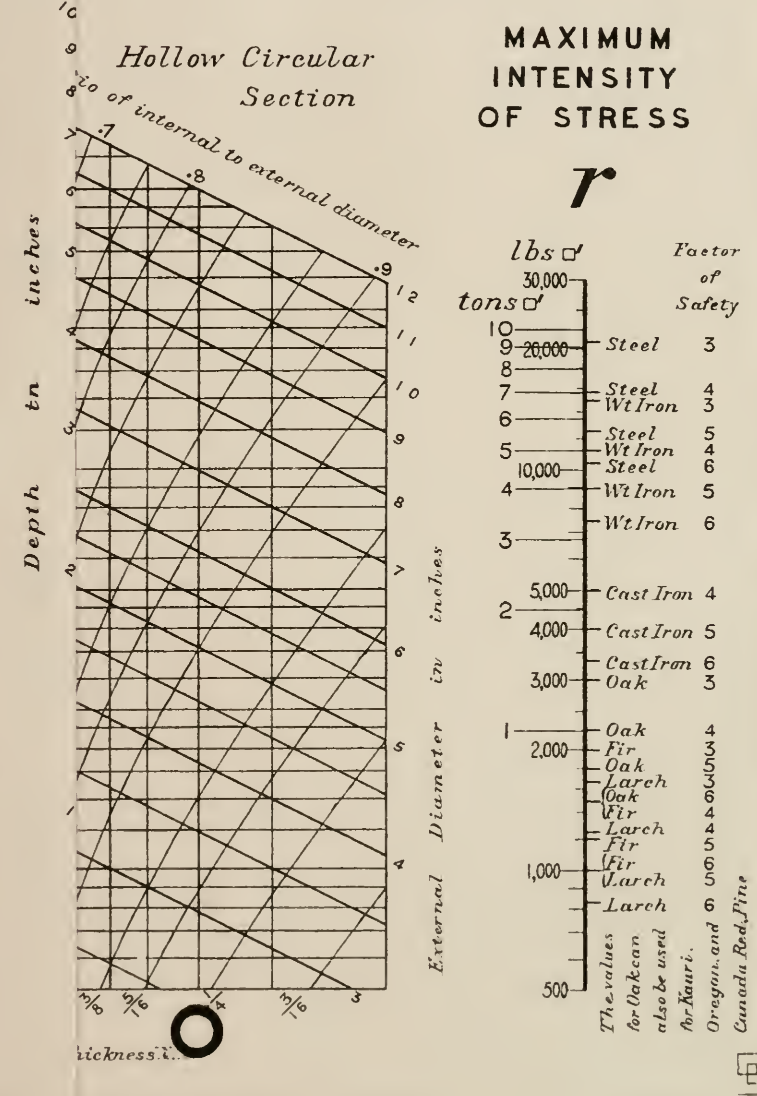
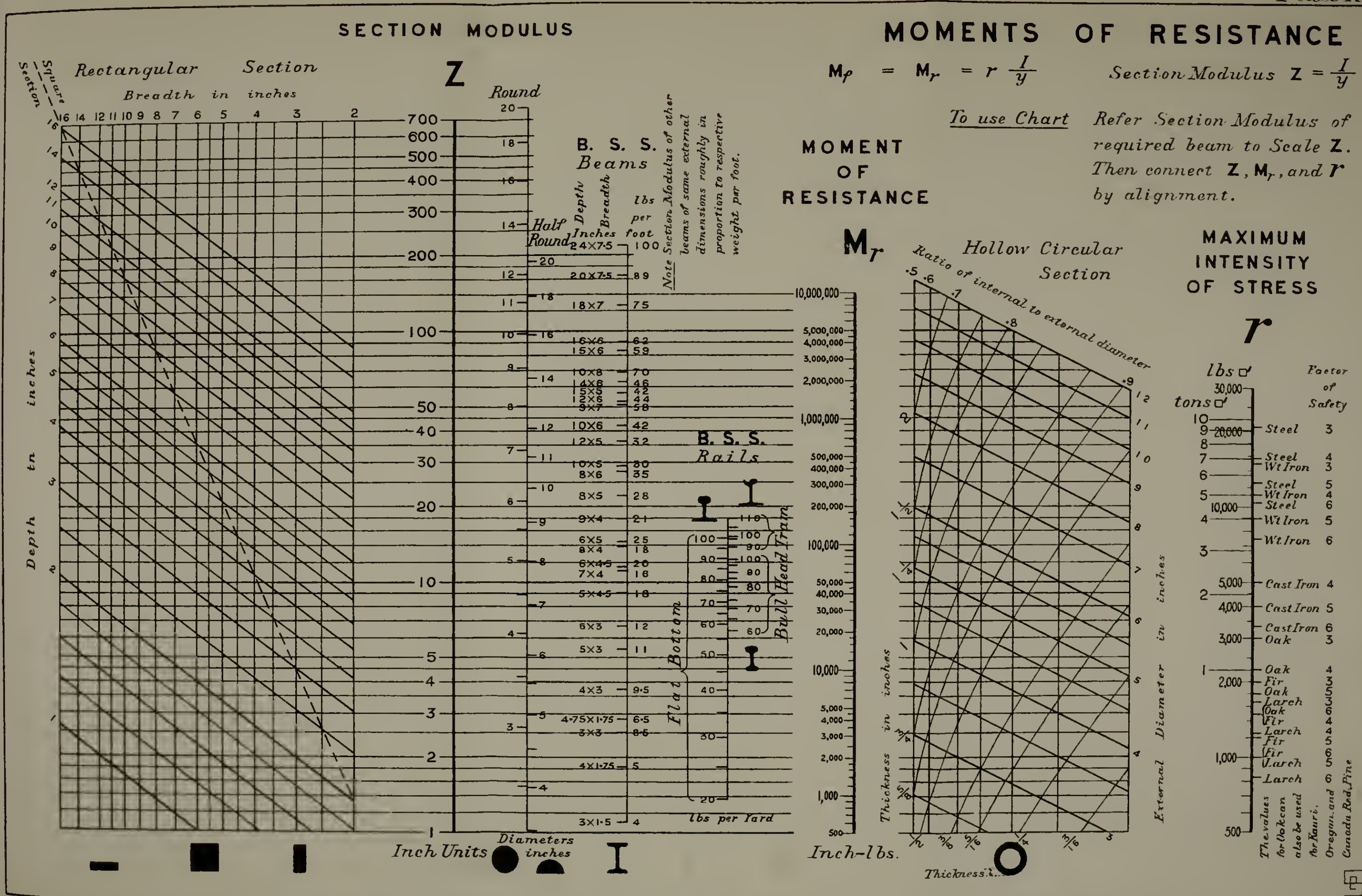


Plate X.


SECTION MODULUS
MOMENTS OF RESISTANCE
$M_p = M_r = r \frac{I}{y}$
Section Modulus $Z = \frac{I}{y}$
To use Chart
Refer Section Modulus of required beam to Scale Z. Then connect Z, M_r, and r by alignment.
Rectangular Section
Square Section
Breadth in inches
Depth in inches
Z
Round
Half Round
Inch Units
Diameters inches
B. S. S. Beams
Depth
Breadth
Inches
lbs per foot
Note Section Modulus of other beams of same external dimensions roughly in proportion to respective weight per foot.
B. S. S. Rails
Flat Bottom
Bull Head Tram
lbs per Yard
MOMENT OF RESISTANCE
M_r
Inch-lbs.
Hollow Circular Section
Ratio of internal to external diameter
Thickness in inches
External Diameter in inches
Thickness
MAXIMUM INTENSITY OF STRESS
r
lbs □"
tons □"
Factor of Safety
Steel 3
Steel 4
Wt Iron 3
Steel 5
Wt Iron 4
Steel 6
Wt Iron 5
Wt Iron 6
Cast Iron 4
Cast Iron 5
Cast Iron 6
Oak 3
Oak 4
Fir 3
Oak 5
Larch 3
Oak 6
Fir 4
Larch 4
Fir 5
Fir 6
Larch 5
Larch 6
The values for Oak can also be used for Kauri. Oregon and Canada Red Pine

GRAPHICAL DETERMINATION OF STRESSES.

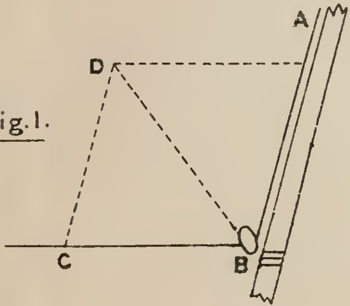


Fig. 1.

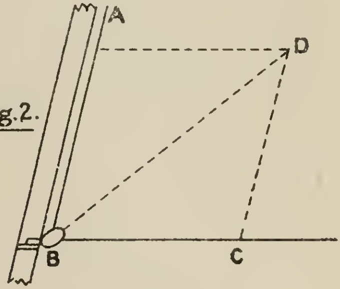


Fig. 2.

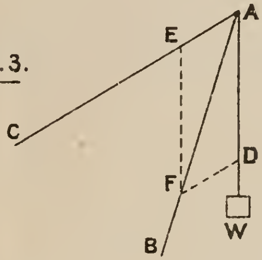


Fig. 3.

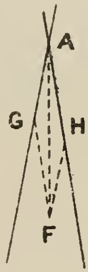


Fig. 4.

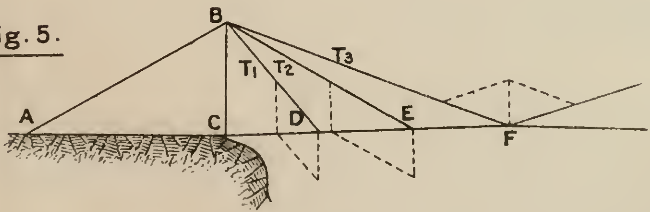


Fig. 5.

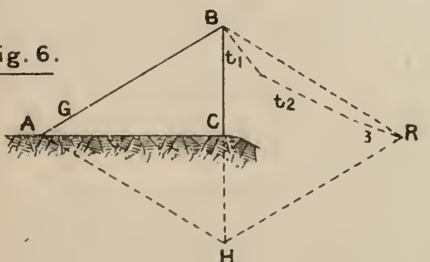


Fig. 6.

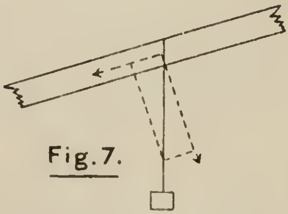


Fig. 7.

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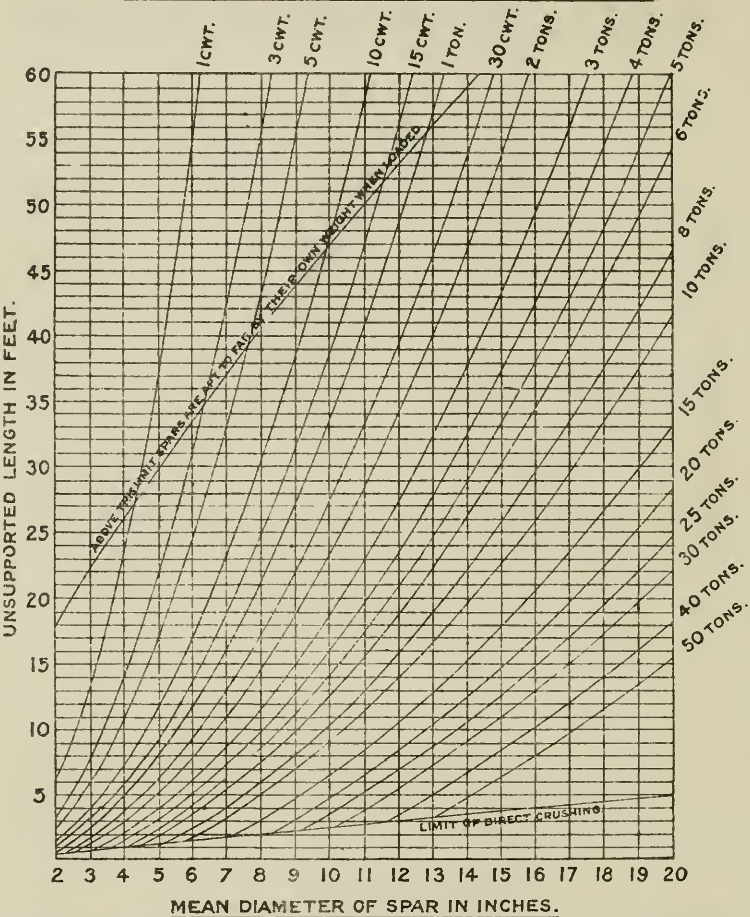
Curves for Compression Members.



This Plate gives the safe Compressions in round Baltic Fir spars. It has been calculated for cases where the ends are "round" or where the fixing is not sufficiently good to consider them "fixed." The probable eccentricity of loading, due to lashings etc. and the effects of live loads, have been allowed for by keeping the safe crushing stress as low as 1,000 lbs. per sq. inch.

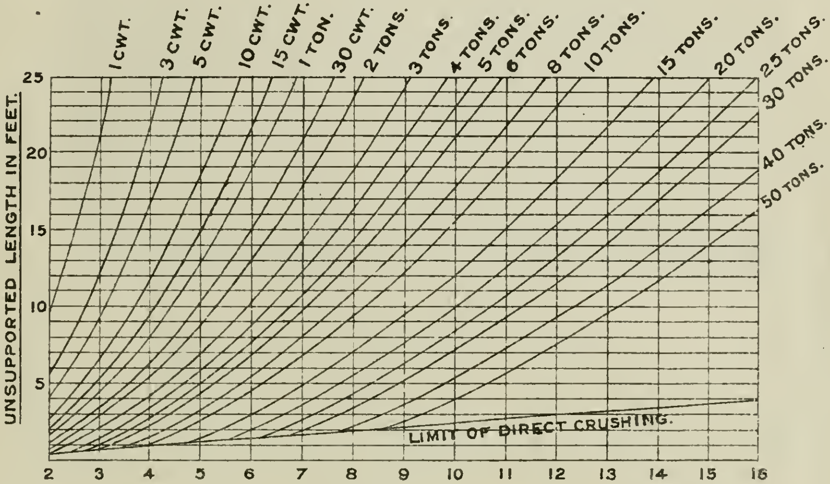
In the case of derricks etc. the compressions in the various members due to a weight W. are as follows, under the most unfavourable circumstances in actual practice

Single derrick,		*1·5 W.*	*Sheers. leg with leading block*	*·9 W.*
Swinging derrick,	*upright spar,*	*2·0 W.*	*do. other leg.*	*·7 W.*
do.	*jib,*	*1·3 W.*	*Gyn, leg with leading block,*	*·6 W.*
do.	*back strut,*	*1·0 W.*	*do. other legs,*	*·4 W.*

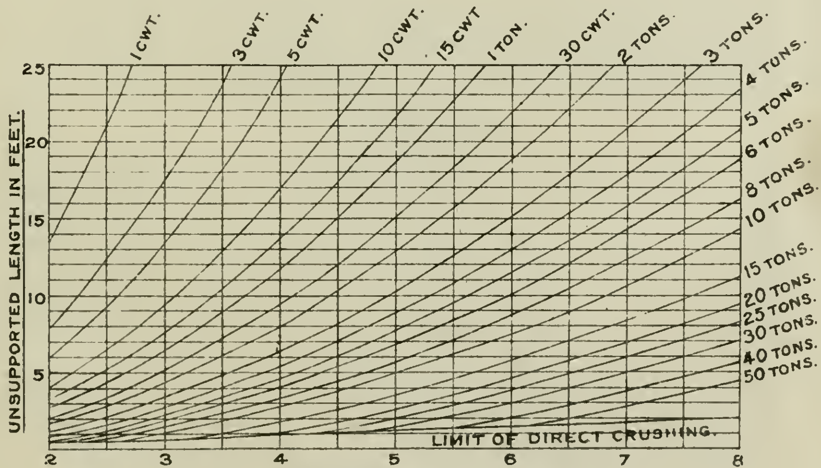
These curves are not applicable to spars that are transversely loaded in addition

Example: To find size of sheer legs 35 feet long to crutch, to lift a weight of 2 tons. Compression in leg with leading block is ·9 × 2 tons = 1·8 tons. Following down between the curves representing 30 cwt & 2 tons, it is seen that the horizontal line representing an unsupported length of 35 feet is met at a point that indicates the use of a spar nearly 12 ins. mean diameter. Compression in the other leg is ·7 × 2 tons = 1·4 tons and in a similar manner the mean diameter of this leg is found to be 11 ins.

CURVES FOR COMPRESSION MEMBERS.



SIDE IN INCHES.
SQUARE BAULKS.



LESSER SIDE IN INCHES.
RECTANGULAR BAULKS SIDES 2 : 1.

This Plate gives the safe Compressions in Baltic Fir baulks. The ends have been considered "Round" & the loading symmetrical. Safe crushing stress taken as 1500 lbs. per square inch. The curves are not applicable to baulks transversely loaded in addition.

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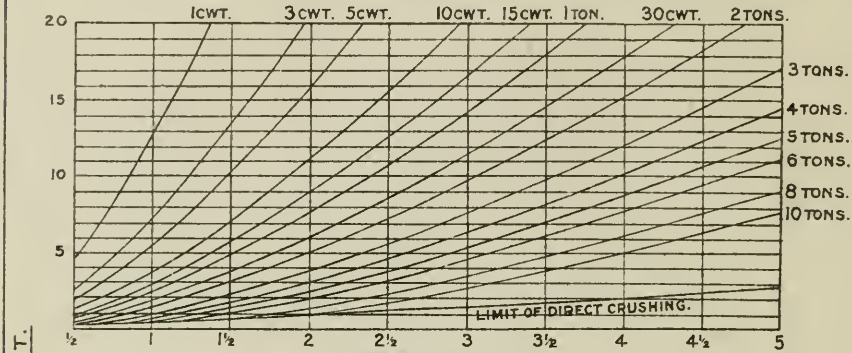
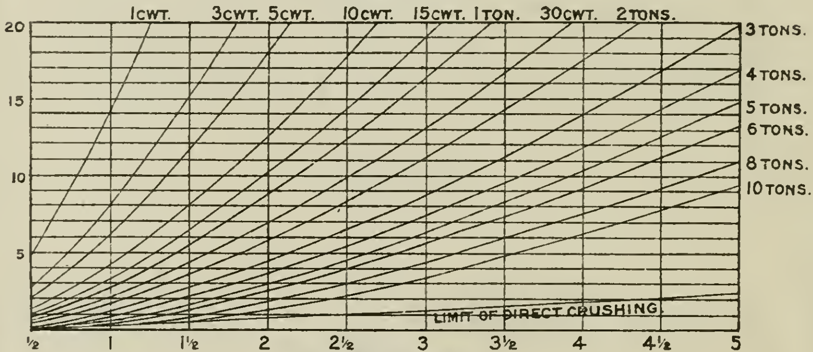
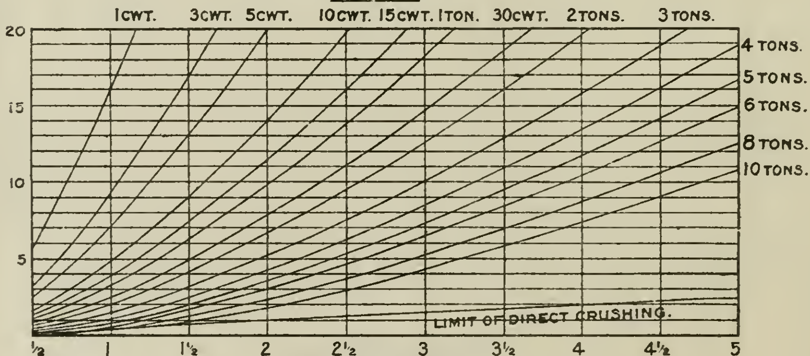
CURVES FOR COMPRESSION MEMBERS.



THICKNESS IN INCHES.
7" BATTENS.



THICKNESS IN INCHES.
9" BOARDS.



THICKNESS IN INCHES.
11" PLANKS.

This plate gives the safe compressions in Baltic Fir planks etc. The ends have been considered "fixed" and the loading symmetrical. Safe crushing stress taken as 1500 lbs. per square inch. The curves are not applicable to planks transversely loaded in addition.

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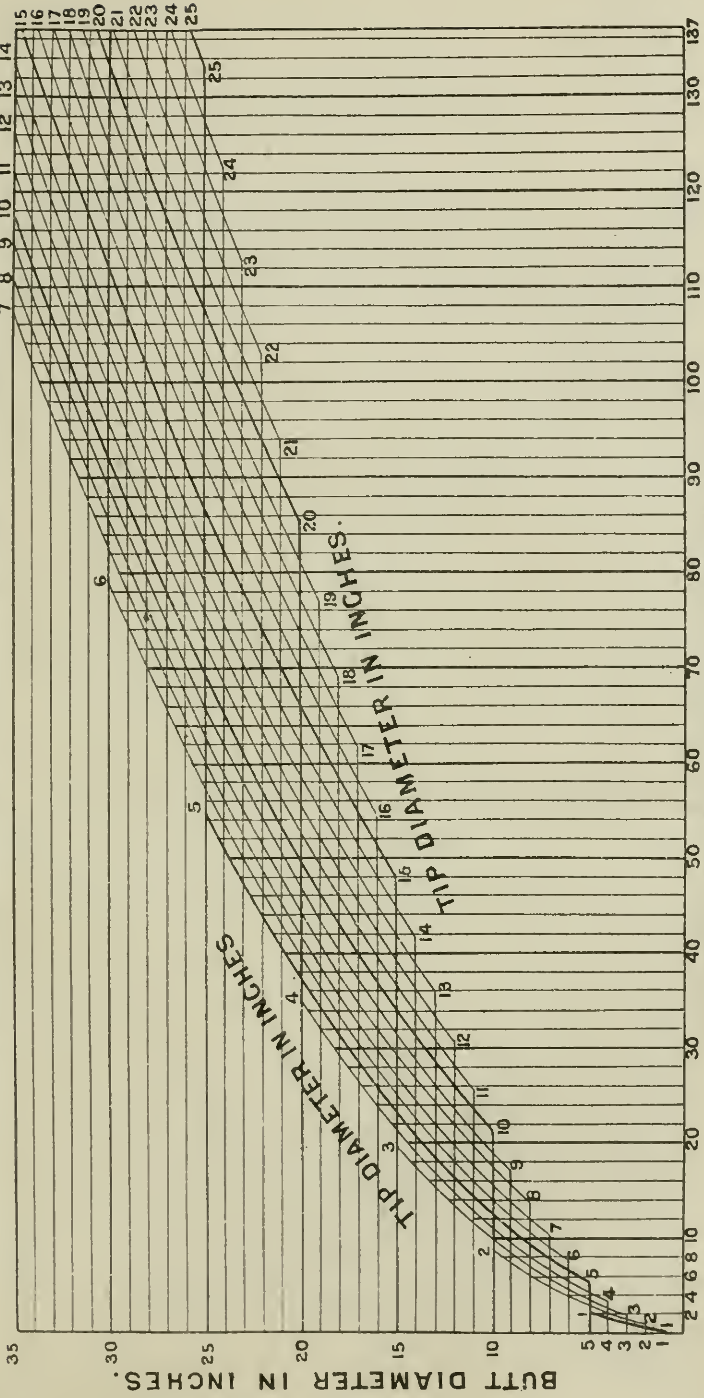
Plate XV.

WEIGHT OF ROUND SPARS OF BALTIC FIR.



NOTE:- FOR OTHER WOODS MULTIPLY THIS VALUE BY $\frac{\text{WT. OF 1 CU. FOOT IN POUNDS}}{39}$

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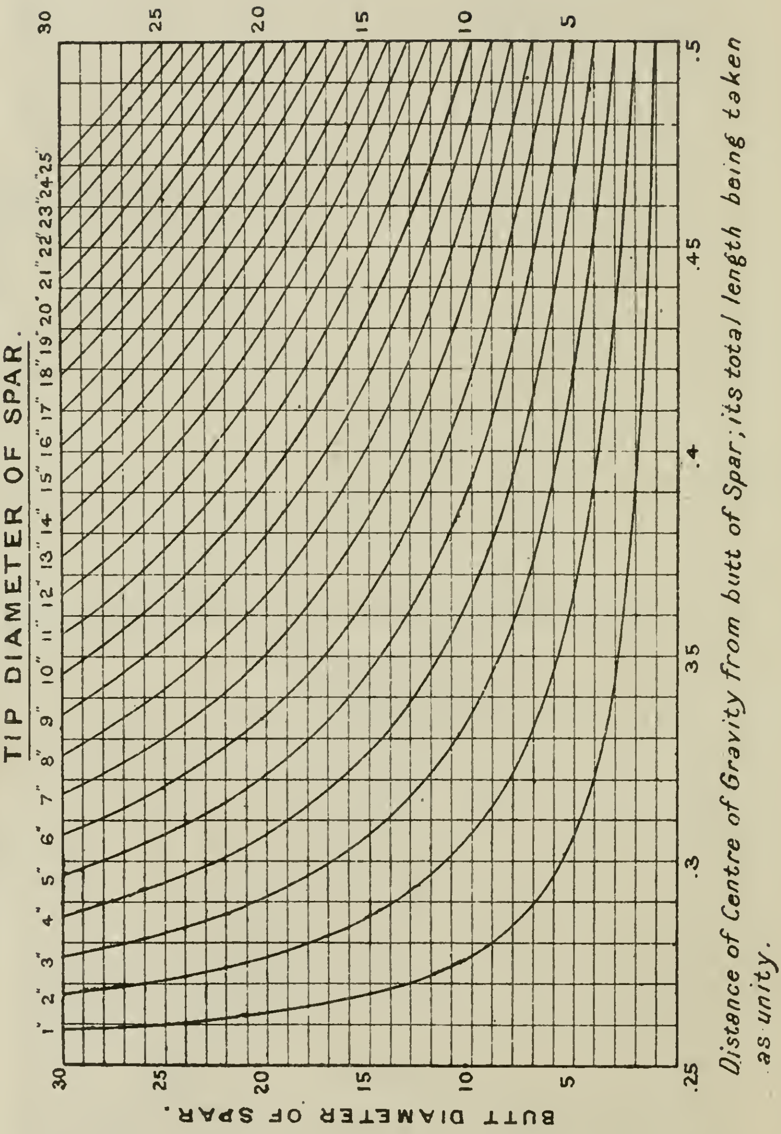
Plate XVI.

CENTRE OF GRAVITY OF ROUND SPARS.



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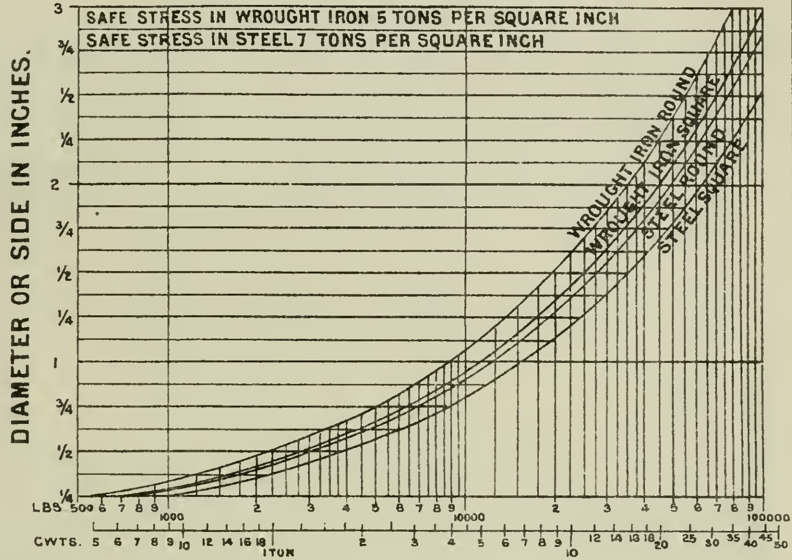
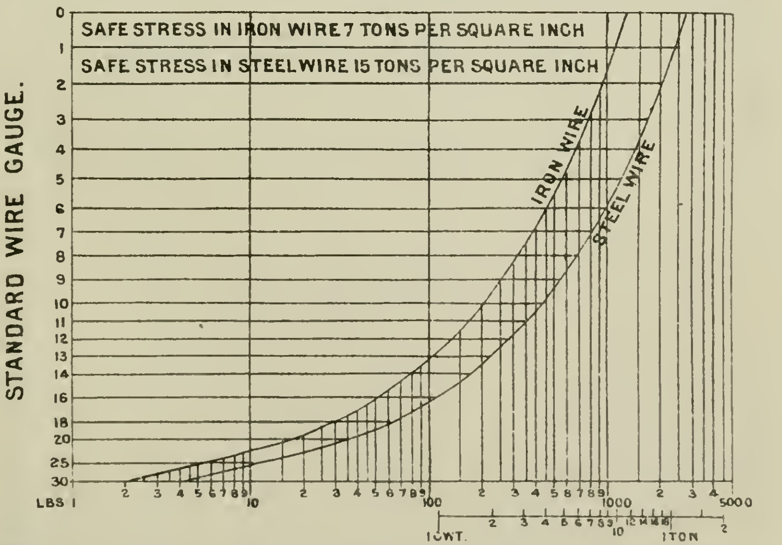
SAFE STRESS IN WROUGHT IRON AND STEEL BARS OF ROUND AND SQUARE SECTION.



SAFE STRESS IN IRON AND STEEL WIRE.



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BRITISH STANDARD SECTION RAILS.

BULL HEADED RAILS.

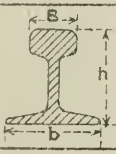
APPROXIMATE VALUES.

$I = \cdot 0118\ Wh^2$

$y = \cdot 530\ h$

$I/y = \cdot 0222\ Wh$

WEIGHT PER YD. W	60	65	70	75	80	85	90	95	100
HEIGHT h	4 3/4	4 7/8	5	5 1/8	5 3/8	5 13/32	5 35/64	5 21/32	5 23/32
UPPER FLANGE B	2 5/16	2 3/8	2 7/16	2 1/2	2 3/16	2 1/16	2 3/4	2 3/4	2 3/4
LOWER FLANGE b	2 5/16	2 3/8	2 7/16	2 1/2	2 9/16	2 11/16	2 3/4	2 3/4	2 3/4
AREA A	5·869	6·338	6·883	7·318	7·802	8·331	8 811	9·284	9·800
I.	16·39	18·67	20·99	23·22	27·4·3	30·18	32·14	35·69	39·47
y.	2·53	2·58	2·65	2·72	2·84	2·89	2·92	3·03	3·16
I/y.	6·47	7·22	7·92	8·53	9·64	10·44	11·00	11·77	12·47



FLAT BOTTOM RAILS.

APPROXIMATE VALUES.

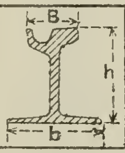
$I = \cdot 0133\ Wh^2$

$y = \cdot 507\ h$

$I/y = \cdot 0263\ Wh$

WEIGHT PER YD. W	20	25	30	35	40	45	50	55	60
HEIGHT h	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	3 15/16	4 1/8	4 5/16
UPPER FLANGE B	1 3/8	1 1/2	1 5/8	1 3/4	1 7/8	1 31/32	2 1/16	2 5/32	2 1/4
LOWER FLANGE b	2 1/2	2 3/4	3	3 1/4	3 1/2	3 3/4	3 15/16	4 1/8	4 5/16
AREA A	1·959	2·449	2 943	3·438	3·925	4·427	4·902	5·376	5·900
I.	1·73	2·55	3 62	4 96	6 54	8·26	10·21	12·28	14·74
y.	1·26	1·38	1·50	1·63	1·76	1·87	1·98	2·07	2·17
I/y	1·37	1·85	2·41	3·04	3·72	4·42	5·17	5·93	6·80

WEIGHT PER YD. W	65	70	75	80	85	90	95	100	
HEIGHT h	4 7/16	4 5/8	4 13/16	5	5 3/16	5 3/8	5 9/16	5 3/4	
UPPER FLANGE B	2 5/16	2 3/8	2 7/16	2 1/2	2 9/16	2 5/8	2 11/16	2 3/4	
LOWER FLANGE b	4 7/16	4 5/8	4 13/16	5	5 3/16	5 3/8	5 9/16	5 3/4	
AREA A	6·367	6·849	7·341	7·847	8·330	8·826	9·302	9·810	
I	17·04	19·74	22·91	26·54	30·38	34·62	39·27	44·42	
y	2·26	2·36	2·47	2·59	2·67	2·77	2·86	2·95	
I/y	7·53	8·35	9·26	10·26	11·36	12·51	13·73	15·05	



TRAM RAILS.

APPROXIMATE VALUES

$I = \cdot 0125\ Wh^2$

$y = \cdot 0531\ h$

$I/y = \cdot 0235\ Wh$

WEIGHT PER YARD W	90	95	100	105	110
HEIGHT h	6 1/2	6 1/2	6 1/2	7	7
UPPER FLANGE B	3 1/2	3 9/16	3 11/16	3 13/16	3 31/32
LOWER FLANGE b	6 1/2	7	7	7	7
AREA A	8·862	9·237	9·844	10·379	10·925
I	47·41	50·79	52·45	63·43	67·75
y	3·43	3·38	3·42	3·81	8·75
I/y	13·83	15·02	15·34	16·64	18·07

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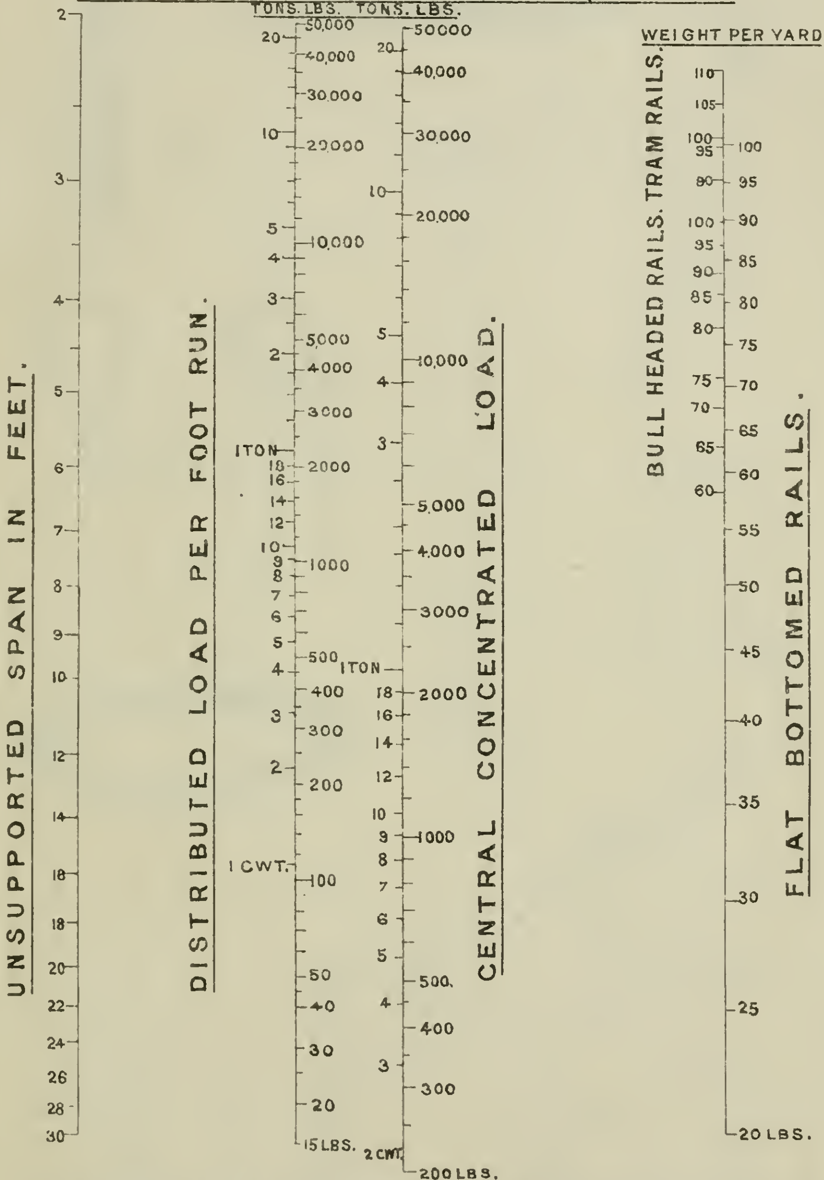
SAFE LOADS ON BRITISH STANDARD SECTION. STEEL RAILS.

SAFE STRESS TAKEN AS 7 TONS PER SQUARE INCH.



Hold straight edge across outer scales. Read result on central scales
The following deductions must be made from the amounts read on central scales :–
<u>Concentrated Load</u> :– Half the <u>total</u> weight of the rail.
<u>Distributed Load</u> :– The weight, per <u>foot</u> run, of the rail.

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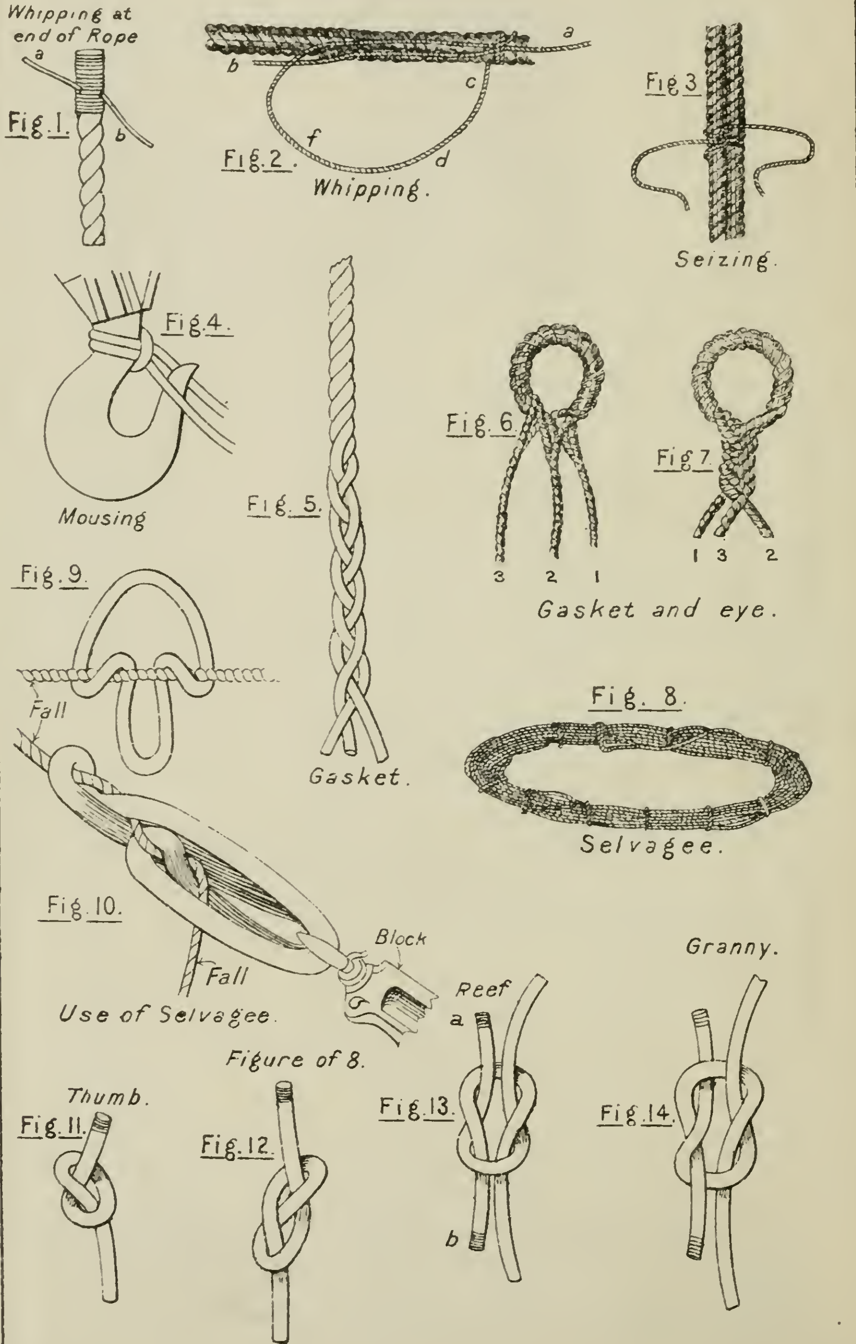
KNOTS.



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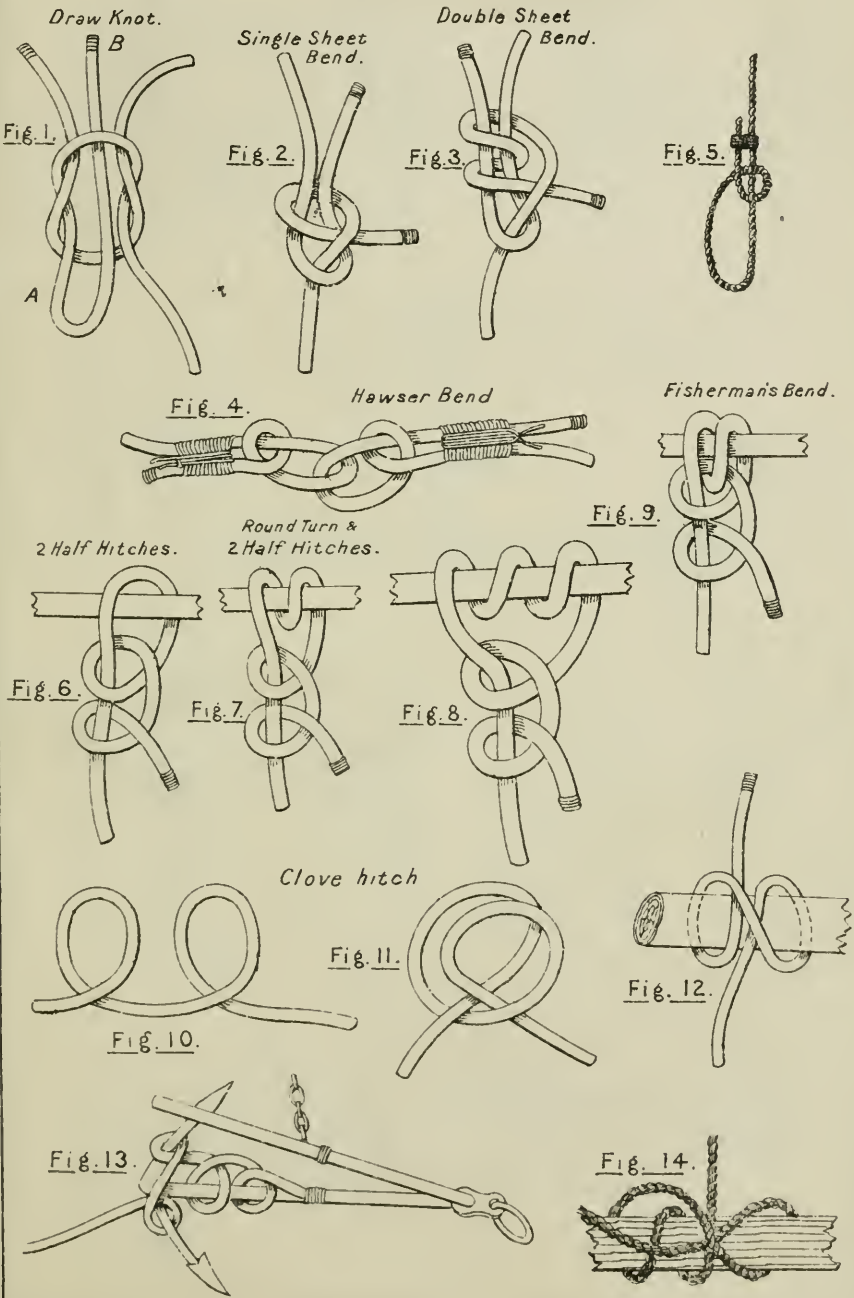
KNOTS.



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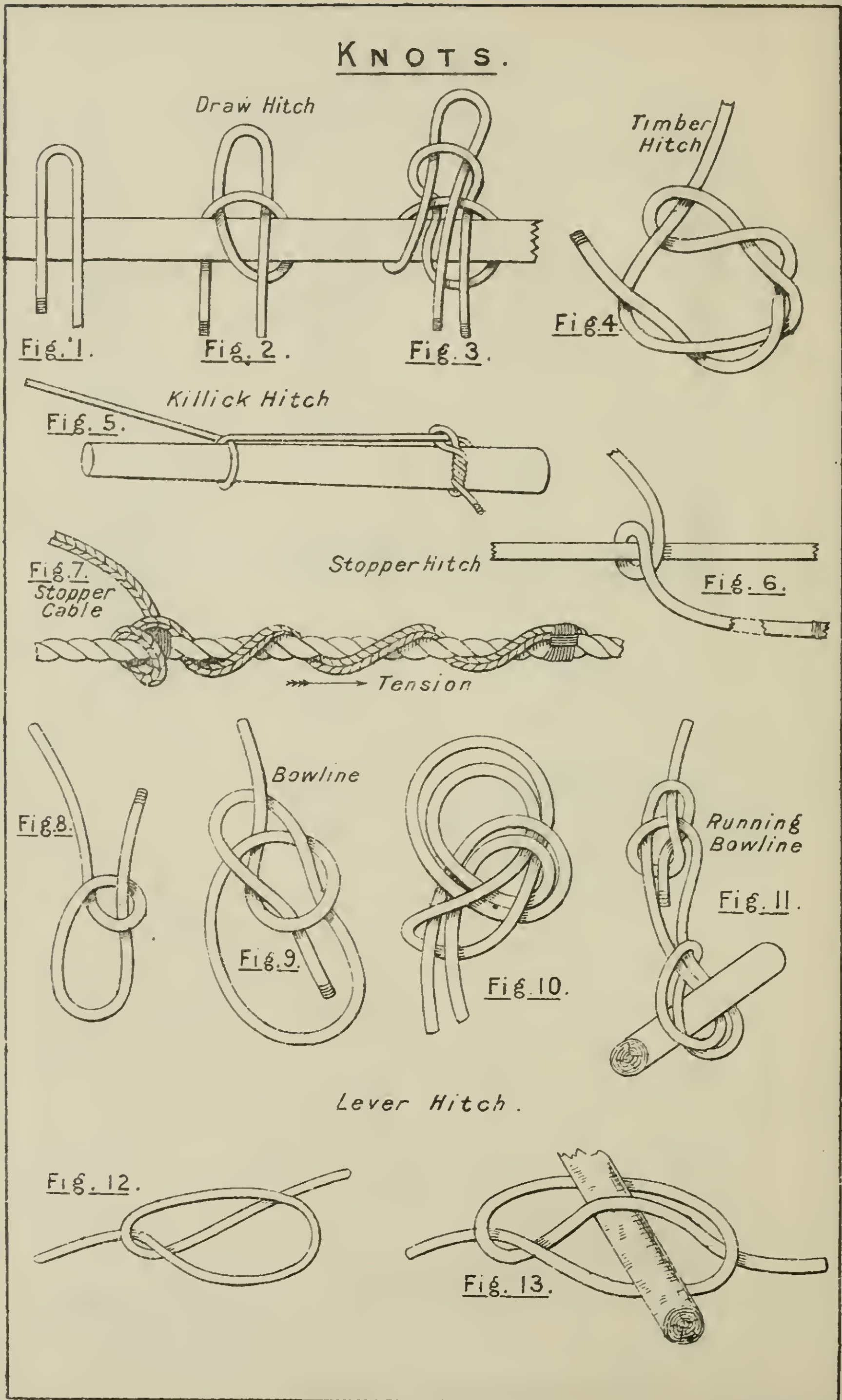

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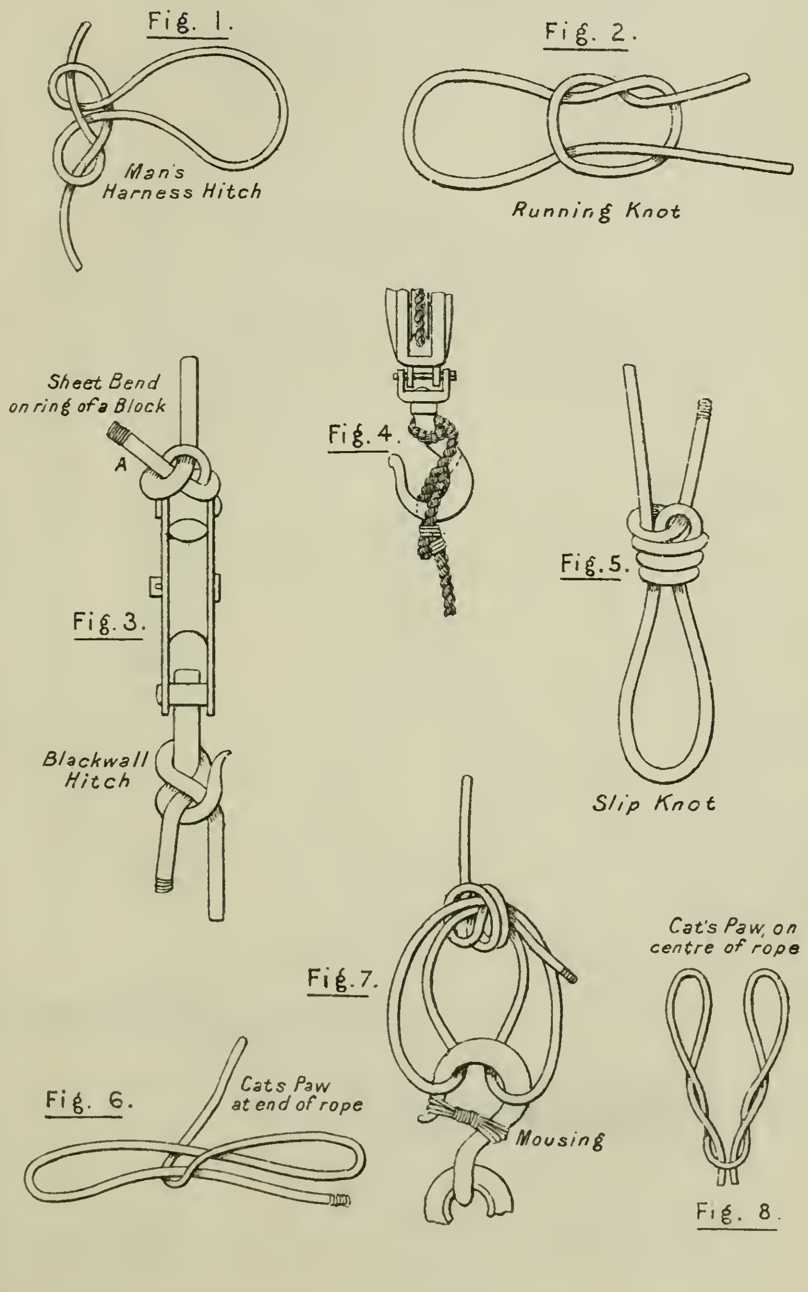
KNOTS.



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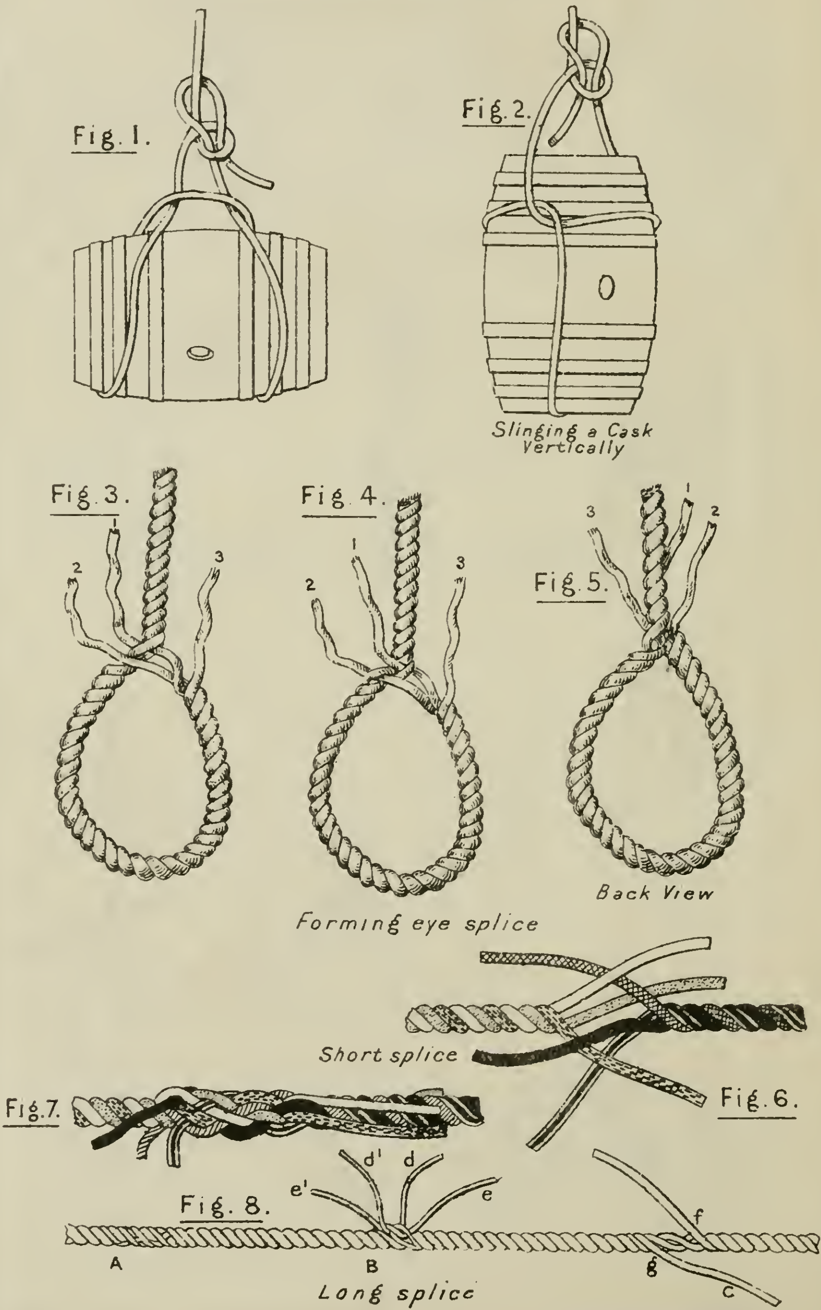
SLINGING. SPLICING.



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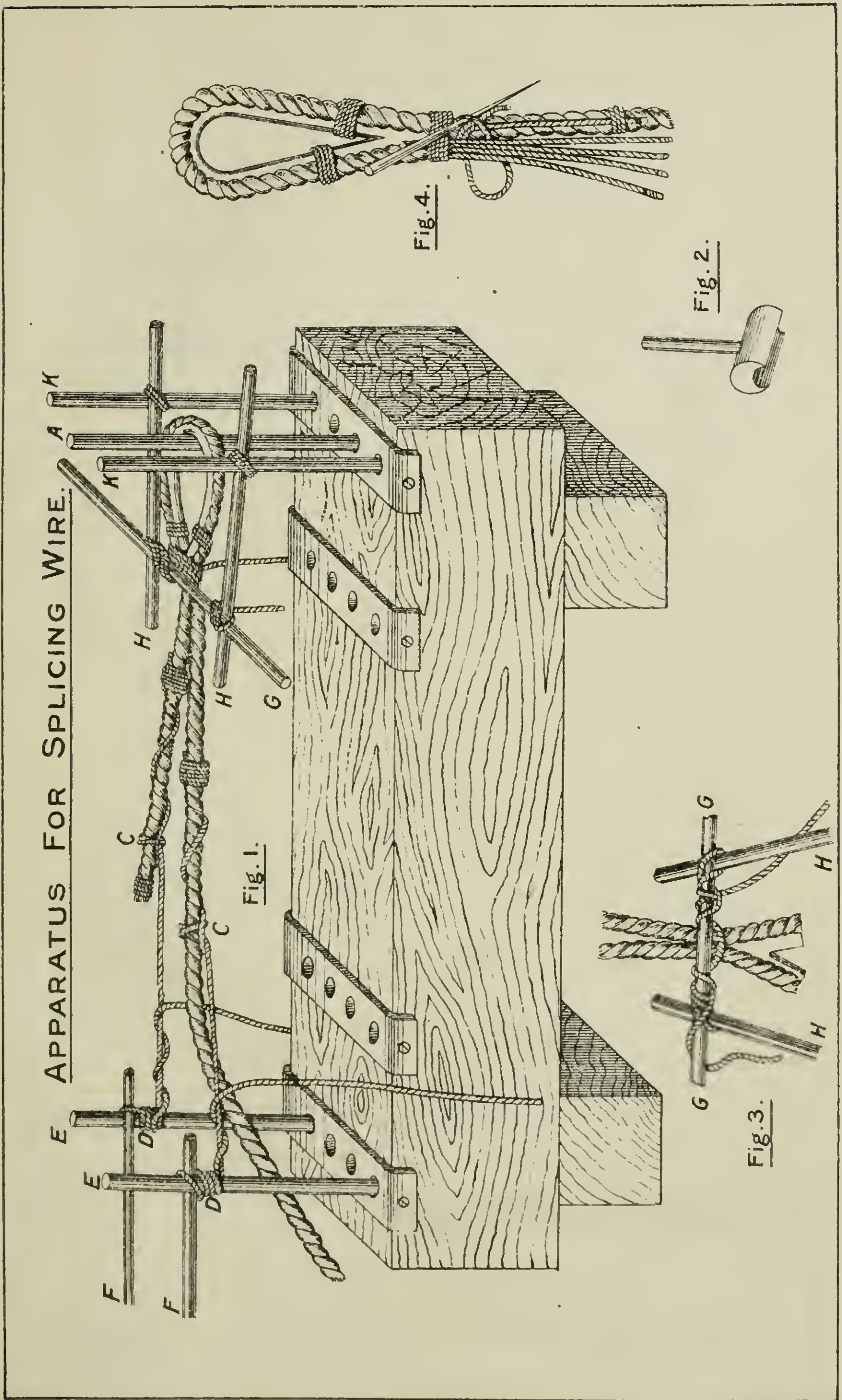

Apparatus For Splicing Wire.

Fig. 1. Fig. 2. Fig. 3. Fig. 4.

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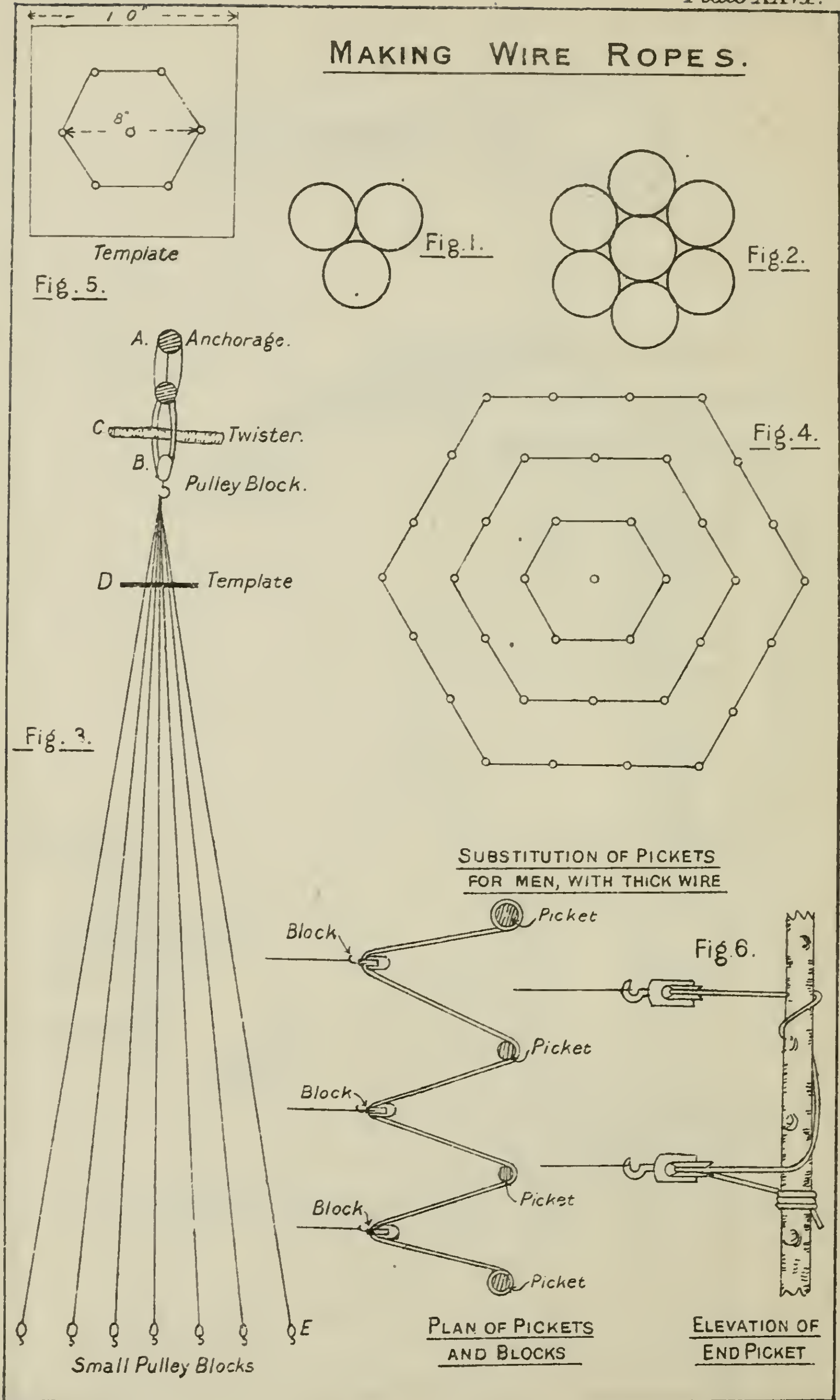
Making Wire Ropes.



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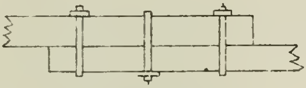
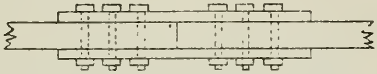
Joints and Fastenings.

Fig. 1.



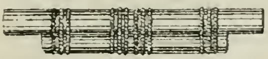
Lapped Joint.

Fig. 2.



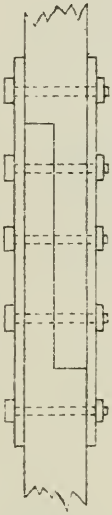
Fished Joint.

Fig. 3.



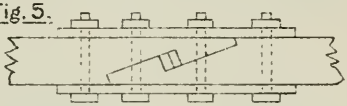
Fished Spars.

Fig. 4.



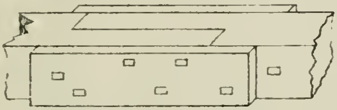
Compression Scarf Joint.

Fig. 5.



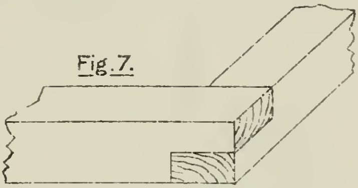
Tension Scarf Joint.

Fig. 6.



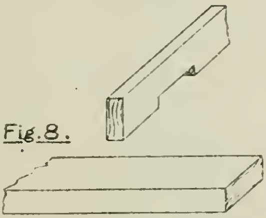
Transverse Stress Scarf Joint.

Fig. 7.



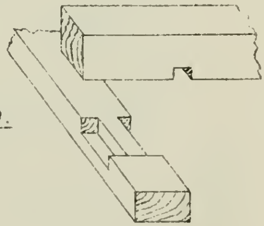
Halved Joint.

Fig. 8.



Notched Joint.

Fig. 9.

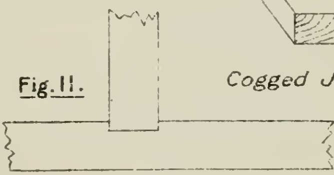


Cogged Joint.

Fig. 10.

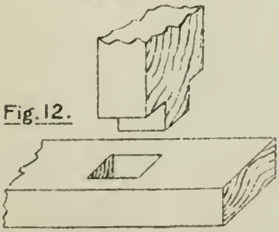
Tusk Tenon.

Fig. 11.



Housing.

Fig. 12.



Mortice & Tenon.

Fig. 13.

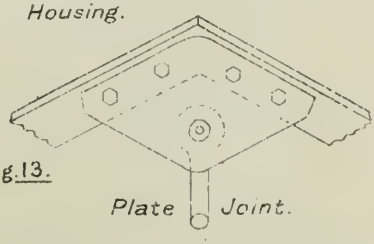


Plate Joint.

JOINTS AND FASTENINGS.

Fig. 1.

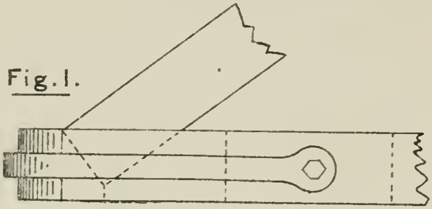
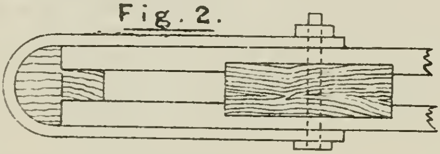
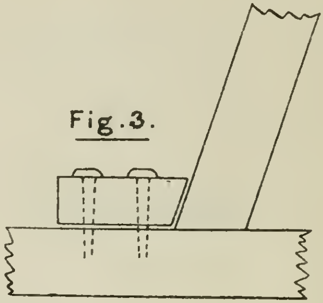


Fig. 2.



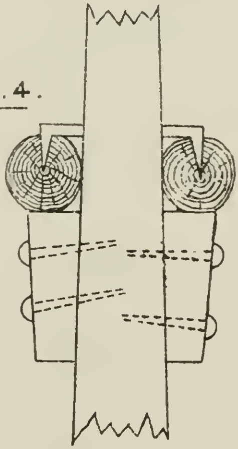
Joint between tie and strut.

Fig. 3.



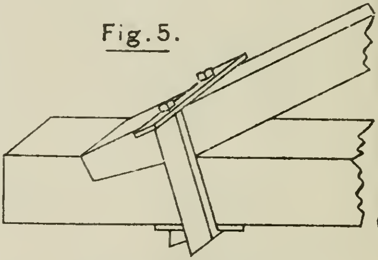
Joint with Cleat.

Fig. 4.



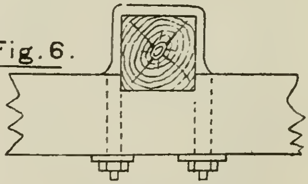
Joint with Cleats on Trestle leg.

Fig. 5.



Strapped Joint.

Fig. 6.

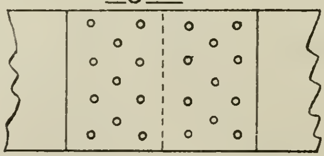


Strapped Joint.

Fig. 7.

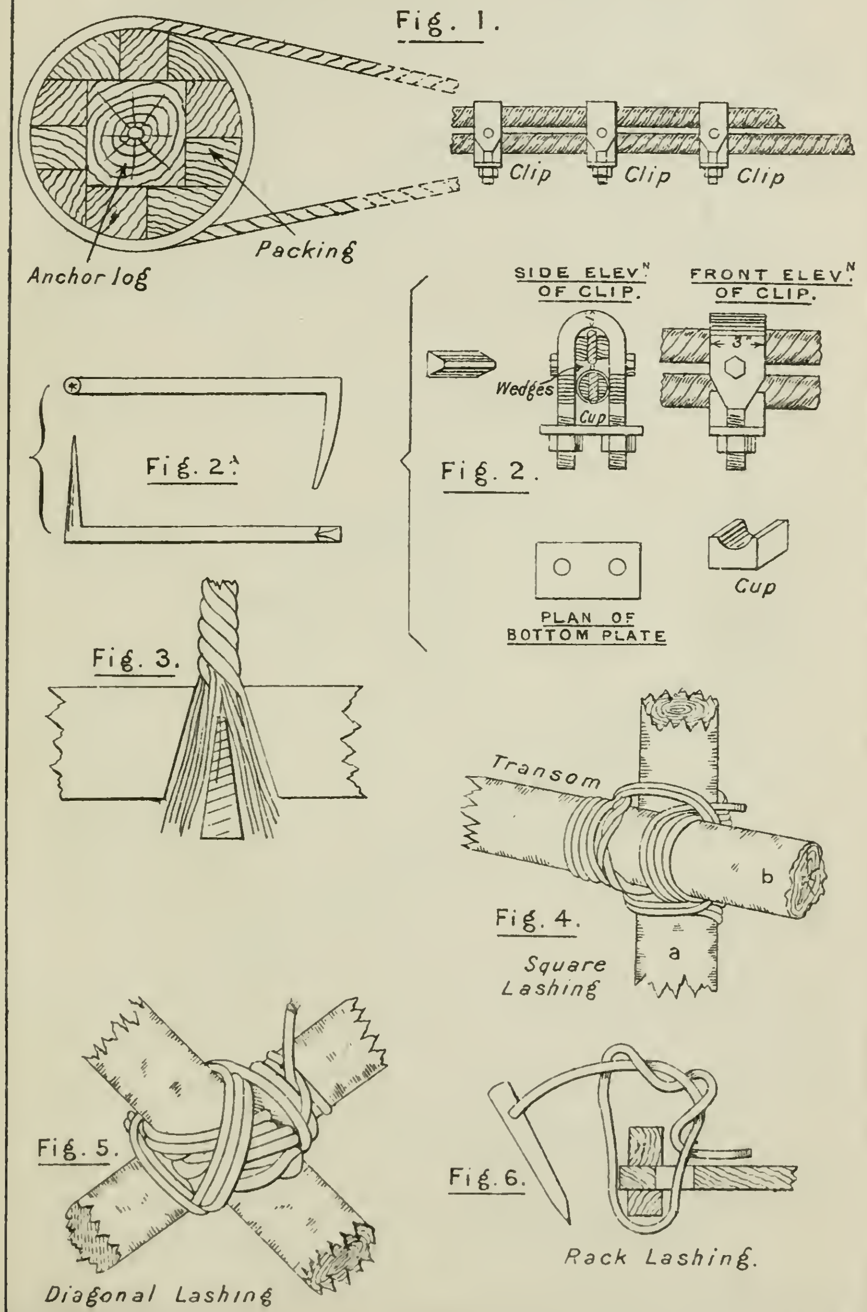
Quadruple chain rivetting.

Fig. 8.

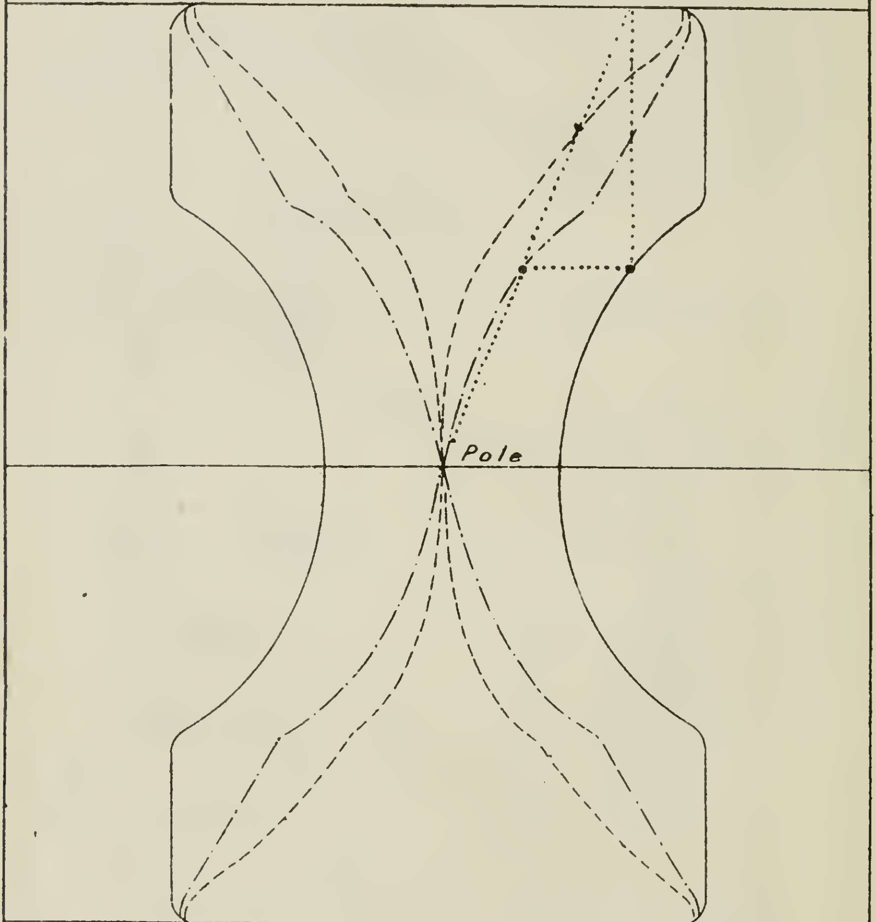


Treble zigzag rivetting.

Wire Rope Fastenings. Lashings.



Graphical Determination of Section Modulus.



Original Section. ————————

First Modified Section. —·—·—·—

Second Modified Section. - - - - - - - -

Construction Lines. ....

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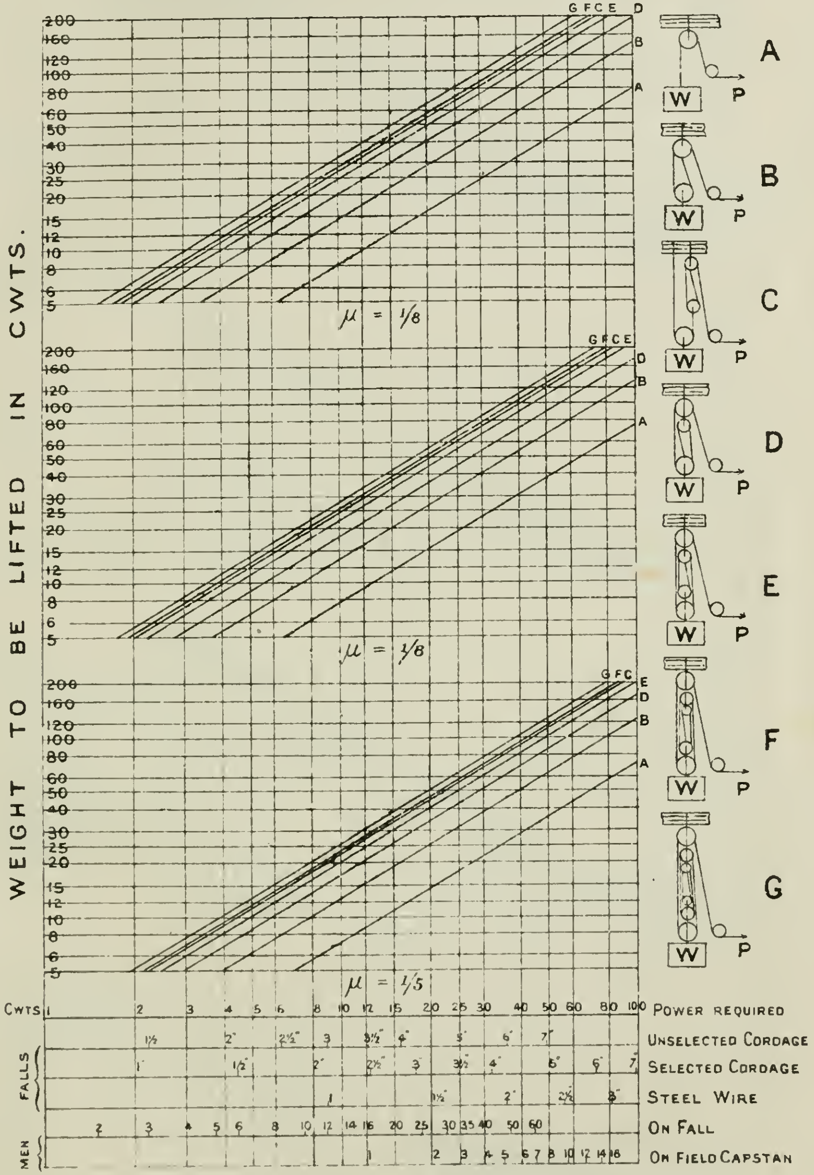
MAIN OR LIFTING TACKLES



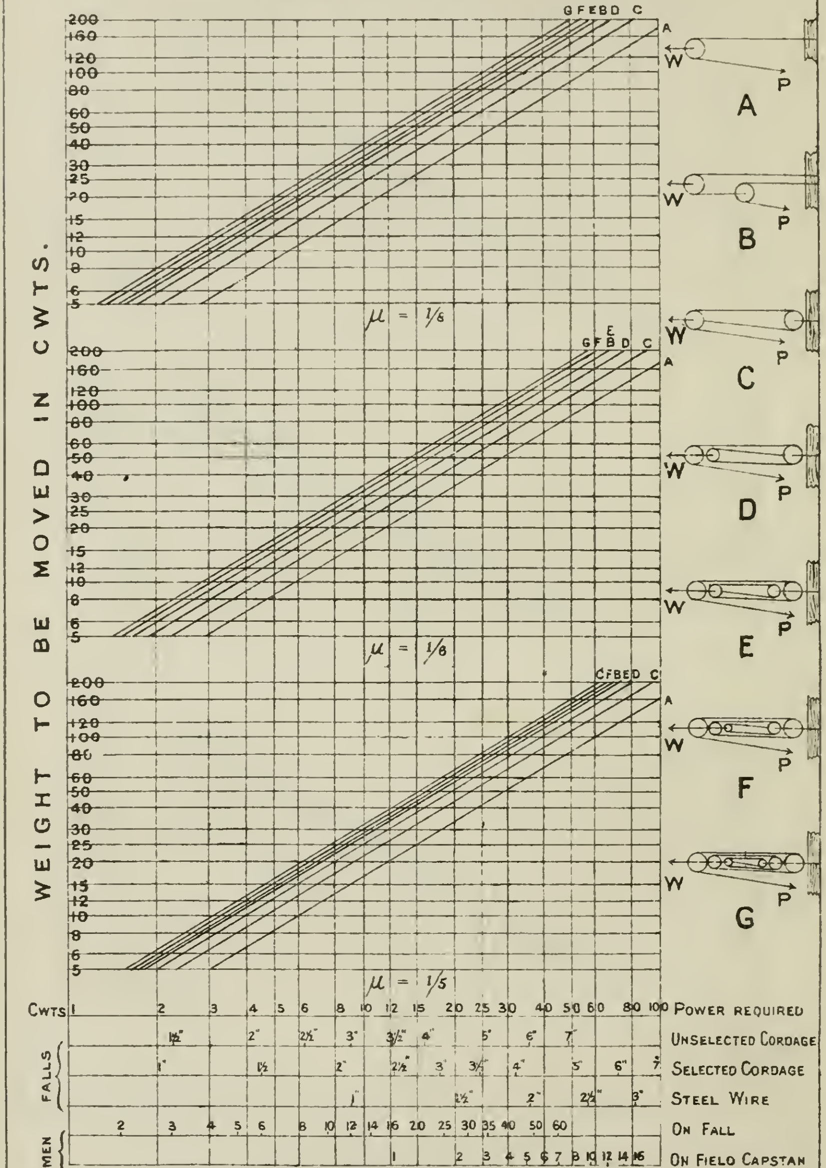
DERIVED FROM THE FORMULA $P = \frac{W}{G}(1 + \mu\, n)$

WHERE P IS THE POWER REQUIRED W THE WEIGHT TO BE LIFTED

G THE THEORETICAL ADVANTAGE n THE NUMBER OF SHEAVES

μ A COEFFICIENT FOR LOSS BY FRICTION AT EACH SHEAVE

RUNNER TACKLES



DERIVED FROM THE FORMULA $P = \frac{W}{G}(1+\mu n)$

WHERE P IS THE POWER REQUIRED W THE WEIGHT TO BE MOVED.

C THE THEORETICAL ADVANTAGE n THE NUMBER OF SHEAVES.

μ A COEFFICIENT FOR LOSS BY FRICTION AT EACH SHEAVE.

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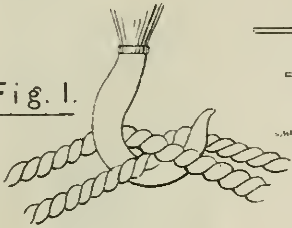
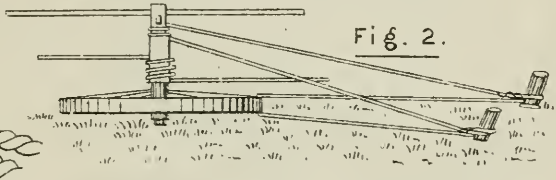
APPLIANCES & ANCHORAGES.

Fig. 1.



IMPROVISED CAPSTAN.

Fig. 2.



DEVIL CART.

FOR MOVING LARGE TIMBER.

Fig. 3.

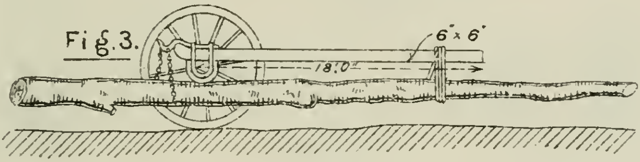


Fig. 4.

ENLARGEMENT OF HOOK in Fig. 3.

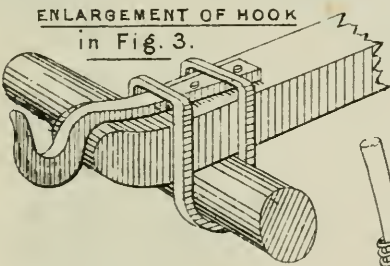


Fig. 5.

3, 2, 1, HOLDFAST.

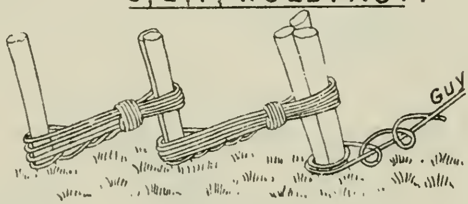


Fig. 6.

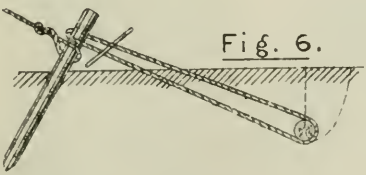


Fig. 7.

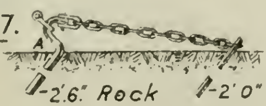
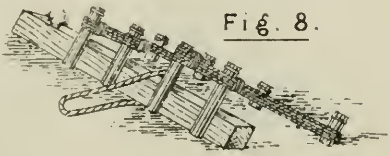


Fig. 8.



ANCHORAGES.

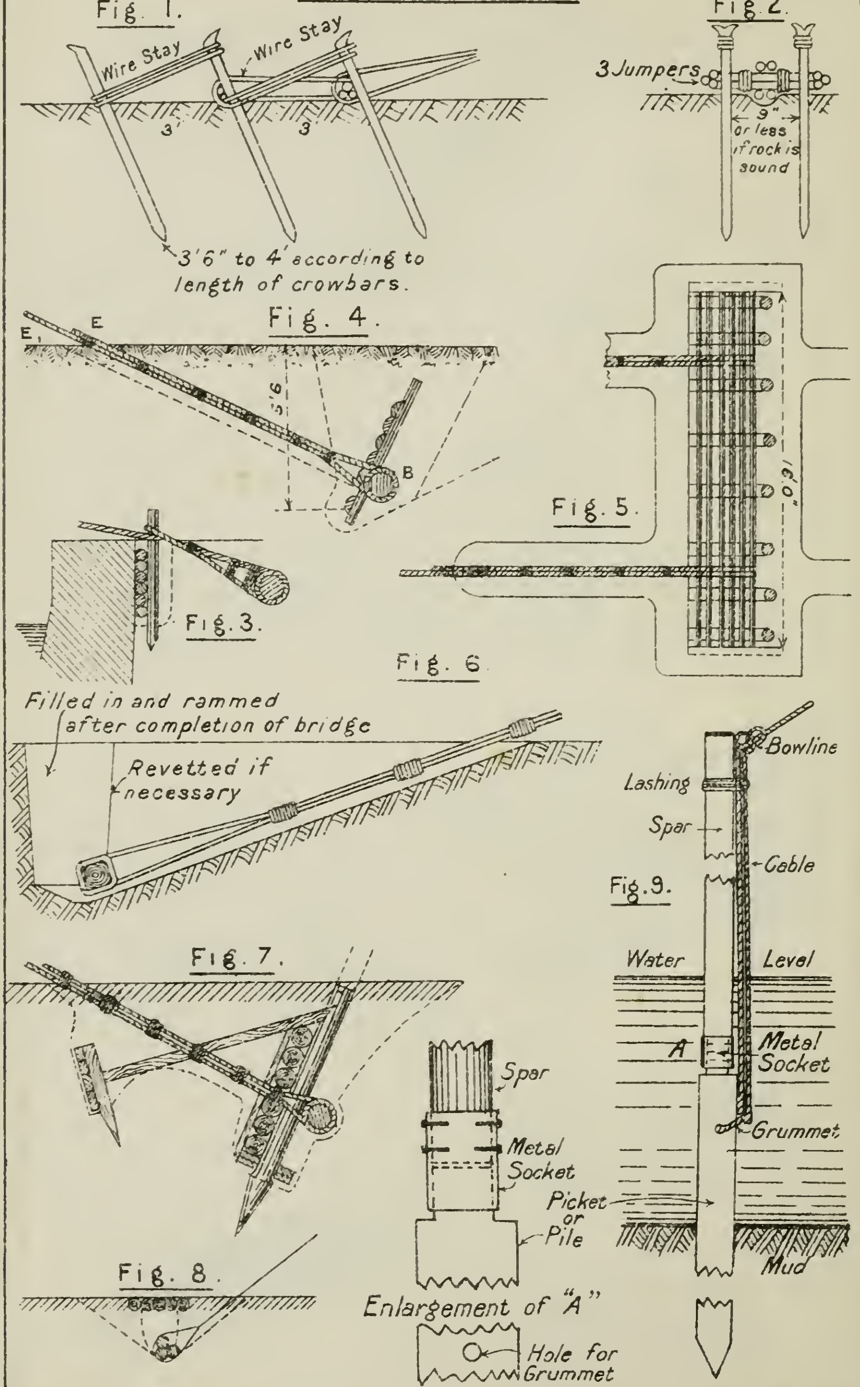
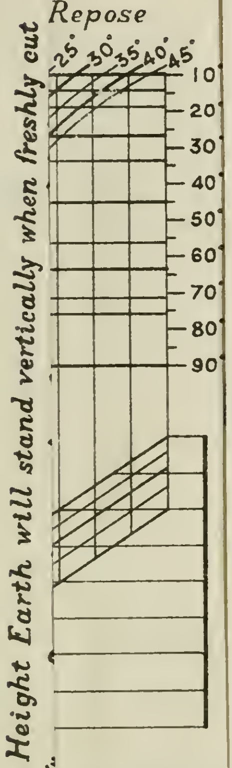


Fig. 1.
Wire Stay
Wire Stay
3'
3'
3'6" to 4' according to
length of crowbars.
Fig. 2.
3 Jumpers
9"
or less
if rock is
sound
Fig. 4.
E
E
3'6
B
Fig. 5.
16'0"
Fig. 3.
Fig. 6.
Filled in and rammed
after completion of bridge
Revetted if
necessary
Bowline
Lashing
Spar
Cable
Fig. 9.
Water
Level
Fig. 7.
A
Metal
Socket
Spar
Grummet
Metal
Socket
Picket
or
Pile
Mud
Fig. 8.
Enlargement of "A"
Hole for
Grummet

AFE RE

T COHES

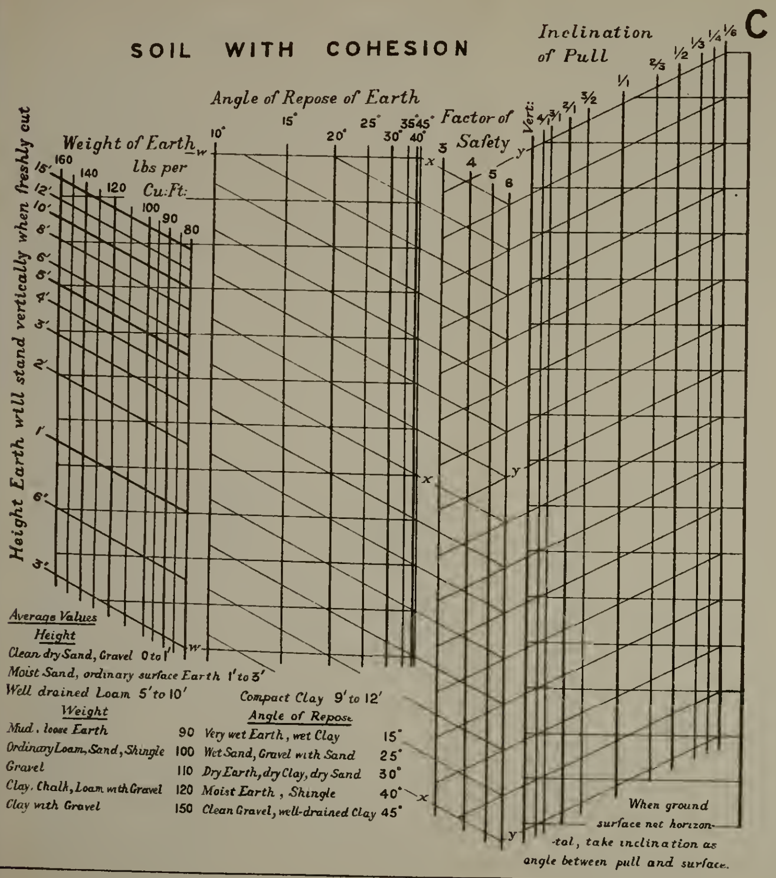


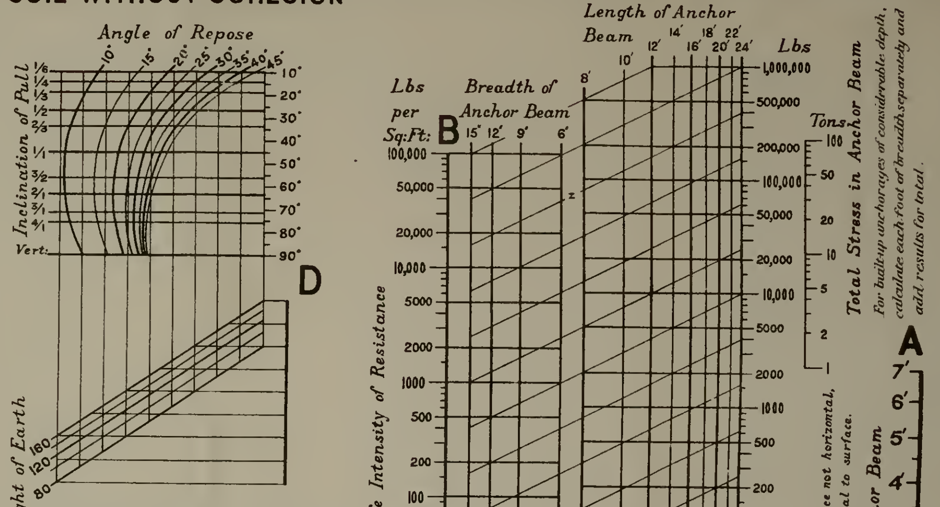
, enter chart by
will stand vertic
Aver met; from interse
es w till vert: re
Clean roceed par: to lin
Moist et; from inter: p
Well o: inclination
horizontally t
Mud am; this will gi
Ordin of anchor beam
Grave rizontally to s
Clay, such as shingle,
Clay proceed vertical
n this point pro
ble to find the

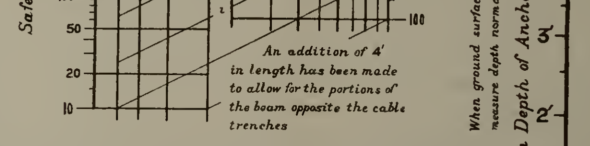
IS
W

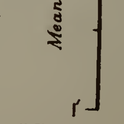
ith.

SAFE RESISTANCE OF BURIED ANCHORAGES









For Soil with Cohesion, enter chart by lines representing height soil will stand vertically till vertical rep: weight is met; from intersection proceed parallel to lines w till vert: rep: angle of repose is met; from inter: proceed par: to lines x till vert: rep: factor of safety is met; from inter: proceed par: to lines y till vert: rep: inclination of pull is met; from inter: proceed horizontally to Scale C. Join this point by a straight-edge to point on Scale A rep: mean depth of anchor beam; this will give safe intensity of resistance on Scale B. Proceed horizontally from this point till vert: rep: breadth of anchor beam is met; from inter: proceed par: to lines z till vert: rep: length of beam is met; from inter: proceed horizontally to scale rep: total safe stress in lbs or tons as required.

For Soil without Cohesion, such as shingle, enter by curved lines rep: angle of repose till horizontal rep: inclination of pull is met; from inter: proceed vertically till inclined lines rep: weight of soil is met; from inter: proceed to Scale D horizontally; from this point proceed as before.

For accuracy it is advisable to find the various intersections by ruling pencil lines on the chart.

DERRICKS.

Fig. 1.

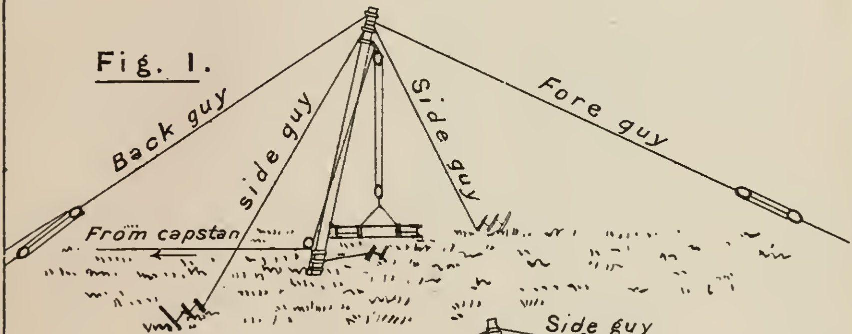
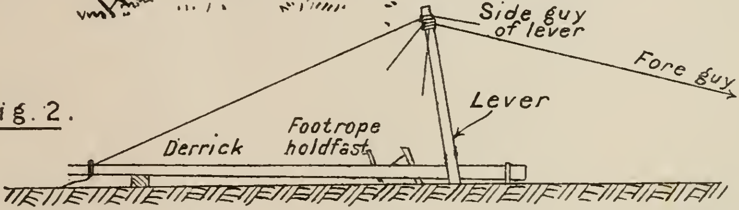


Fig. 2.



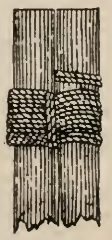


Fig. 3.

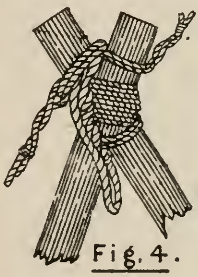
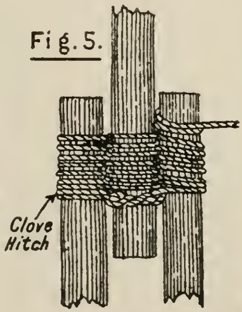


Fig. 4.

Fig. 5.



Note:- Frapping turns are omitted so as to show the lashing.

Fig. 6.

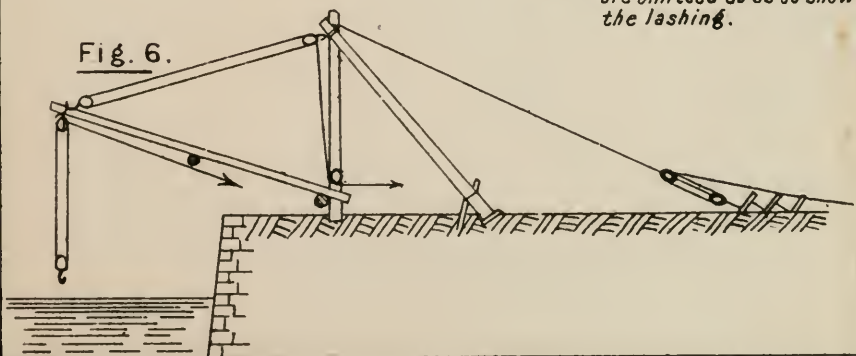
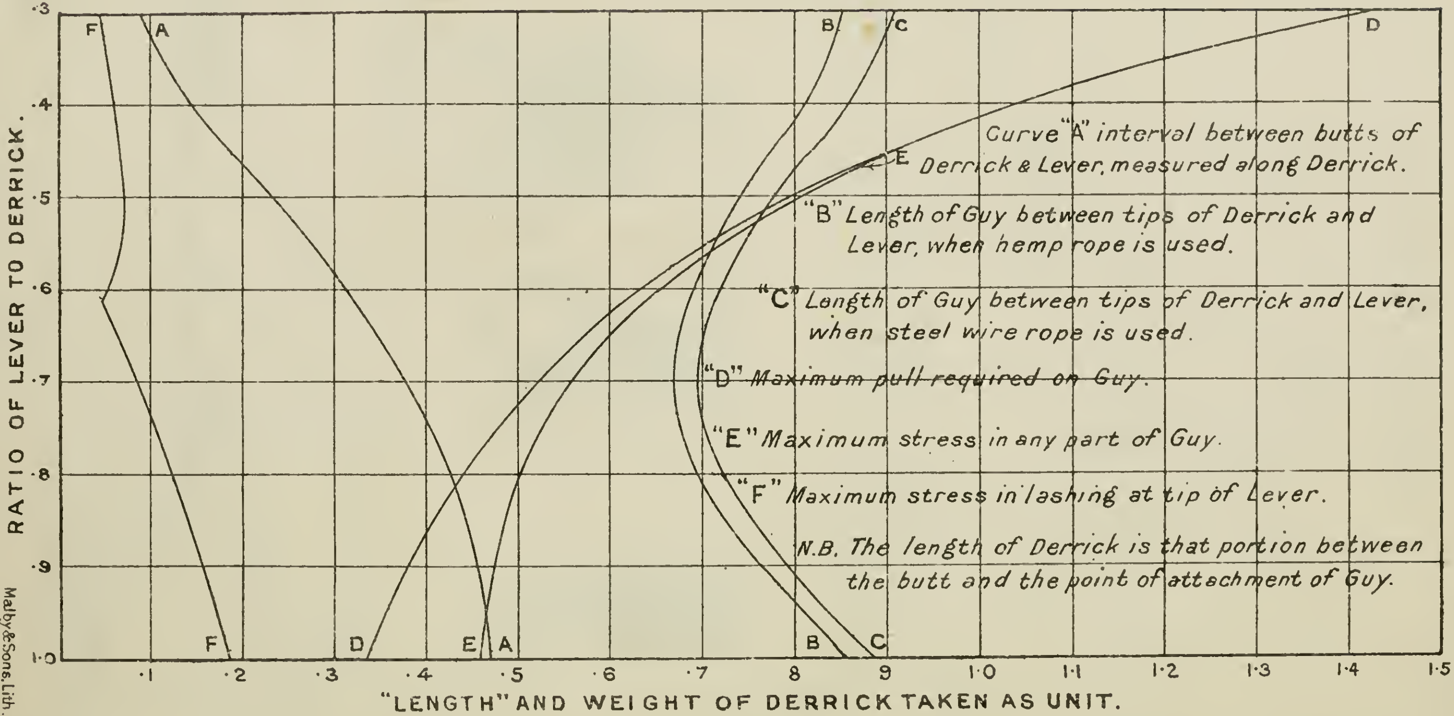


Plate XXXVII.

Raising Derricks and Sheers by Levers.



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DERRICKS AND SHEERS.

Fig. 1.

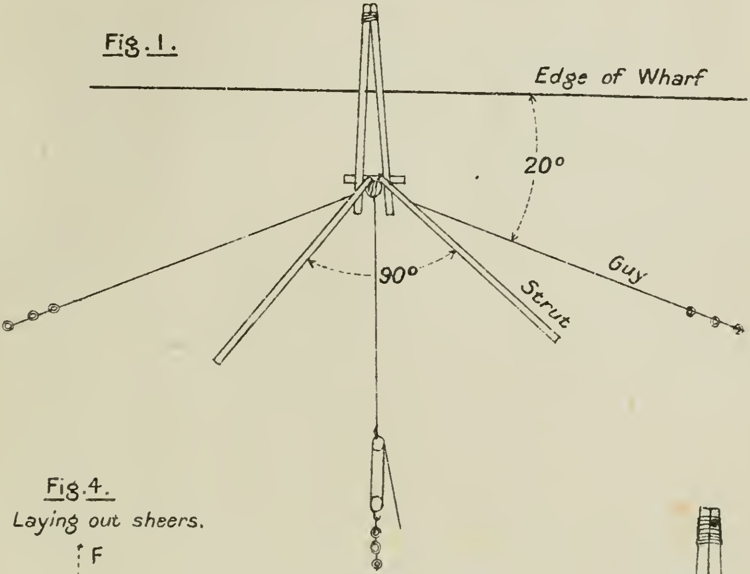
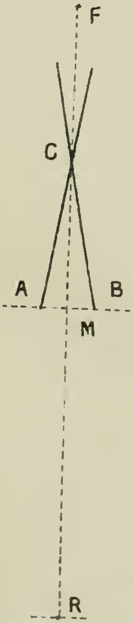


Fig. 4.
Laying out sheers.



M.R.=M.F.-2 A.C.
A.B.=$\frac{1}{3}$ A.C.

Fig. 3.

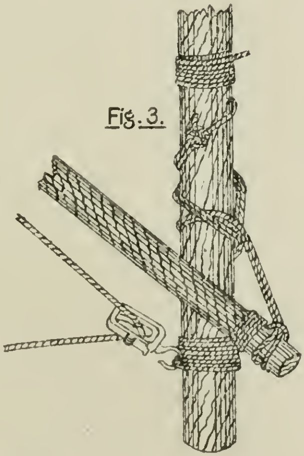
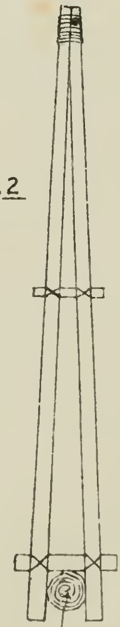
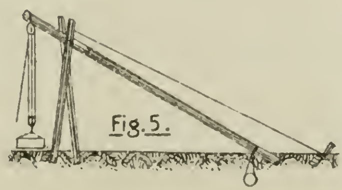


Fig. 2.



Upright Spar

Fig. 5.



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